1-1-2017

Southern Yellow Pine In-Grade Lumber Evaluation

Tâmara Suely Filgueira Amorim França

Southern yellow pine in-grade lumber evaluation

By

Tâmara Suely Filgueira Amorim França

A Dissertation
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in Sustainable Bioproducts
in the Department of Sustainable Bioproducts

Mississippi State, Mississippi

August 2017

Southern yellow pine in-grade lumber evaluation

By

Tâmara Suely Filgueira Amorim França

Approved:

R. Dan Seale
(Major Professor)

Rubin Shmulsky
(Minor Professor)

Dragica Jeremic Nikolic
(Committee Member)

Robert J. Ross
(Committee Member)

Abdolhamid Borazjani
(Graduate Coordinator)

George M. Hopper
Dean
College of Forest Resources

Name: Tâmara Suely Filgueira Amorim França

Date of Degree: August 11, 2017

Institution: Mississippi State University

Major Field: Sustainable Bioproducts

Major Professor: R. Dan Seale

Title of Study: Southern yellow pine in-grade lumber evaluation

Pages in Study: 80

Candidate for Degree of Doctor of Philosophy

The southern pine species group is the main softwood resource used in the U.S, and the majority of southern pine is used in lumber production. The use of lumber in structural purpose requires feasible strength and stiffness grading method ensuring characteristics allowable stress values. The stiffness and strength of most of southern pine lumber is assessed using visual grading system. The objective of this study was to evaluate a production weighted sample of 2 × 4, 2 × 6, 2 × 8, and 2 × 10 No. 2 grade southern pine lumber collected across its geographic range. The results of this research show a snapshot of the material commercially sold in the southern U.S. region. Over one third of the specimens contained pith, and had an average mean value of 4.6 for number of rings per inch (RPI) and 43.8% for latewood (LW). The overall specific gravity (SG), modulus of elasticity (MOE) and modulus of rupture (MOR) were 0.54, 10.1 GPa, and 41.7 MPa, respectively. The allowable design bending strength (F_b) for 2 × 4, 2 × 6, 2 × 8, and 2 × 10 was 11.2, 9.2, 8.1, and 7.1 MPa, respectively. Specimens containing no pith, RPI higher or equal then 4.0, and LW higher or equal then 33.0% were greater in MOE and MOR. The effect of grading controlling characteristics of the material was also studied. The presence of knots had the most significant impact on mechanical properties.

Specimens with wane and shake had greater SG, MOE, MOR, F_b values than specimens with others grading controlling characteristics. The mean values found for RPI, LW, and SG met the requirements recommended for southern pine No. 2 lumber. The MOE and F_b values found therein met the previous and the new allowable design value. The results of this research can be used to identify and to select the best variables to improve the prediction of bending properties of visually graded lumber.

Keywords: grading system, mechanical properties, controlling characteristics.

DEDICATION

I would like to dedicate my dissertation to God without whom nothing is possible. I would also like to dedicate my dissertation to my beloved husband, parents, grandparents, and siblings in Brazil.

ACKNOWLEDGEMENTS

First and foremost I would like to thank God. I would like to thank my major professor, Dr. Roy Daniel Seale for having faith in my ability and for giving me this opportunity. I would like to thank the committee members, Dr. Rubin Shmulsky, Dr. Robert J. Ross, and Dr. Dragica Jeremic for their advices and support. I would like to thank David Kretschmann for his guidance throughout the project. I also would like to thank Dr. Michael Barnes that gladly took the time to share his knowledge with me.

I would also like to thank Theodore Alexander, John Black, Edward Entsminger, Jeanie McNeel, Kay Davidson and Brian Mitchell for their kind selfless support, guidance and encouragement.

I would like to acknowledge the support of U.S. Department of Agriculture (USDA), Research, Education, and Economics (REE), Agriculture Research Service (ARS), Administrative and Financial Management (AFM, Financial Management and Accounting Division (FMAD) Grants and Agreements Management Branch (GAMB), under Agreement No. 5B-0202-4-001. Any opinions, findings, conclusion, or recommendations expressed in this publication are those of the author and do not necessarily reflect the view of the U.S. Department of Agriculture.

To my dear husband, Frederico França for his unfailing love and support. Special thanks to my grandparents, Geraldo (*in memorian*) and Maria Celeste Filgueira for their unconditional love. To my parents, Norma and Antônio Amorim, and my siblings, Tânia and Anderson for their love and encouragement. To Spain and Standefer family for their guidance and support. I would like to thank all professors and friends I had along the journey of my studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Wood is a biological material; consequently, its properties are influenced by a variety of factors that cannot be controlled. Genetics and various environmental factors interact in complex ways during the development of wood within a living tree. Knowledge of mechanical properties of wood and wood products such as lumber are essential for the proper and efficient use of this material.

The major southern pines (*Pinus taeda*, *P. palustris*, *P. echinata*, and *P. elliottii*) are the principal components of what is referred to as the southern pine species group. The high utility, strength, stiffness and treatability makes the southern pine the most important species and used lumber in the Southeast (Gaby 1985).

Because of the variation within species, grading is necessary to minimize differences between the materials. Mackay (1981) states that the purpose of grading rules is to maintain a standard value between mills manufacturing the same or similar woods yielding a product with a uniform quality. Visual grading and machine grading are the two methods used to grade lumber. The use of these two methods allows a producer to make more efficient use of the available lumber source.

Visual grading method is the most commonly used technique to grade structural lumber, and it determines the allowable design values that are assigned to various grades. Visual grades are based on the properties of clear wood from the species grouping, and the estimated effect of various growth and manufacturing defects on the strength of lumber products from these species (Montero et al. 2011). This type of classification can be made by a manual operation or an automatic grading system.

Machine grading combines visual assessment with a nondestructive evaluation to predict the mechanical properties of wood. Machine grading provides a more precise grading, and also produces lumber with lower coefficient of variation than visual grading (Brown et al. 1997; Winistorfer and Theilen 1997). The lumber processed by machine grading achieves higher design values, which is not possible through visual grading alone (Green et al. 1994).

Visually graded southern pine has high variability within grade thus making it necessary to evaluate the quality of this material (SPIB 2010). This study evaluates the wood properties of in-grade No. 2 southern pine lumber and investigates potential ways of improving visual grading methods thus improving mechanical property evaluation techniques.

1.1 Lumber grading system

The design properties associated with stress grades are edgewise bending modulus of elasticity (MOE), tensile strength, compression parallel to the grain, compression perpendicular to the grain, shear parallel to the grain, and extreme fiber stress in bending. In order to ensure that structural lumber conforms to allowable engineering design property values, these values are measured or inferred through nondestructive evaluation processes such as visual grading criteria, nondestructive tests such as flat-wise bending stiffness or density, or a combination of these methods (Kretschmann et al. 2010; Ross 2015).

Tests of a representative sample of full-size members or small clear specimens are the methods used to establish the mechanical properties of visually graded lumber. In the U.S., the design properties for the major commercial lumber species groups use a mix of these two methods. For example, the current design specification and codes for softwood dimension lumber species are derived from full-size member test results using D 1990 Standard Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens (2016). On the other hand, tests on small clear samples and standard D 245 Standard Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber (ASTM 2011) are still used to derive design properties for most hardwood dimension and structural timbers (Shelley 1989; Green and Kretschmann 1991; Antony et al. 2015).

1.2 History of visual grading and in-grade testing of structural lumber

Visual evaluation is the oldest and most common type of grading performed on lumber in the U. S. In 1895, the first standardization of grading procedures for the design of railway structures, was implemented by the American International Association of Railway Superintendents of Bridges and Building. Prior to that, the U.S. did not have a standardized grading system for solid-sawn structural lumber (Berg et al. 1907). In 1898, the American Society for Testing and Materials (ASTM) was formed, marking the beginning of standards that are used today. The ASTM Committee on Standard Specifications for the Grading of Structural Timber was formed in 1905 (originally Committee Q, which was later changed to Committee D7 in 1910). At that time, ASTM D7 was responsible for developing grading rules. The USDA Forest Service (FS) was studying how the rules could be applied in practice. In 1915, a set of grading rules was developed by the FS (Betts 1915) based on results from a study conducted by Cline (1912).

The American Lumber Standard Committee – ALSC (originally the Committee on Lumbers Standards, U.S. Department of Commerce) was formed in 1922. In 1924 the ALSC produced the first national standard for lumber sizes and grades "Simplified Practice Recommendation No. 16." The objective of this document was to standardize nomenclature and visual characteristics of wood members, and standardization of dimensions. That document provided no information on allowable design values for structural lumber or timbers (Shelley 1992).

In 1923, the USDA Forest Service Forest Products Laboratory (FPL) published the first document that outlined visual grading criteria with assigned stress values for structural lumber (Ivory et al. 1923). The first tentative standard for visual grading rules was written in 1926 and then a full standard in 1927, ASTM D 245, "Standard Methods for Establishing Structural Grades for Visually Graded Lumber." It was based on work completed by Newlin and Johnson (1923) and its objective was to establish codes to select material for structural uses.

Grades, and corresponding design values, were derived by testing small clear specimens of various wood species, and then applying adjustment factors based on visual growth and manufacturing characteristics such as slope of grain, knots and the presence of splits, checks, or wane. The adjustment factors were created through an extensive testing program that was designed to define the effect these characteristics have on the performance of structural lumber (Green and Evans 2001).

Visual grading rules were originally based on tests of small clear specimens from old-growth trees. This resulted in specimens comprised of mostly mature wood. Consequently, the effect juvenile wood has on the performance properties of structural lumber was not well known (Madsen 1992).

To meet the demand for wood products, landowners supply trees which are often grown on managed plantations. Due to their geographical distribution, southern pine trees can grow relatively quickly with appropriate silvicultural practices. It is now widely known that silvicultural practices can have a significant impact on the growth and yield of southern pine timber (Antony et al. 2015). However, any change in the growth of a tree can result in changes to the wood properties and, consequently in the quality of wood products (Zobel and Van Buijtenen 1989).

Southern pine trees grown in intensively managed plantations tend to be harvested in short age rotations, which can result in lumber containing more juvenile wood than lumber obtained from trees harvested from old-growth stands (Larson et al. 2001). Additionally, lumber mills now have technologies to process smaller-diameter logs (Zobel 1984), which contain a large proportion of juvenile wood (Dahlen et al. 2014). These factors led to concern about arose concerning a change in the performance characteristics of southern pine structural lumber (Antony et al. 2015) resulting in testing and re-evaluation of the allowable design values.

In light of changes in the forest resource and lumber manufacturing technologies, during the 1970-1980 time frame, an extensive testing and analysis program was conducted to evaluate the structural properties of full-size dimension lumber. The "In-Grade" program was a cooperative effort by the FPL and various universities and lumber grading agencies. The program's goal was to develop a more accurate way for deriving allowable property values for visually graded lumber (Green and McDonald 1993). Results obtained from the program revealed that adjusted property values based on tests conducted using small clear samples were approximately 35% greater than those actually observed in structural lumber. It also revealed that full-size tests of lumber can more accurately estimate the mechanical properties of in-grade lumber, which can result in more reliable design values (Madsen 1992).

1.3 Objectives

Accurate grading systems are extremely important to avoid over- or under-grading problems which can bring safety issues or reduce efficiency by unnecessarily downgrading pieces thereby causing needless economic loss. In order to evaluate and improve the prediction of bending strength properties of the most significant material used in the market, an evaluation of visual grading methodologies in southern pine No. 2 grade lumber was conducted.

The sample collected was meant to be a representative sample of the global population of visually graded southern pine structural lumber weighted by production. It was not the intention of this research to develop design values of southern pine structural lumber but to evaluate the material commercially sold in the southern U.S. region. The specific objectives of this research were:

- To assess bending strength and stiffness properties of southern pine No. 2 lumber collected across the geographic range in 2 × 4 and 2 × 6 sizes
- To determine the best fit statistical distribution for specific gravity (SG),

modulus of elasticity (MOE) and modulus of rupture (MOR) of visually graded southern pine lumber

- To determine the effect of growth and grade controlling characteristics in flexural properties of southern pine structural lumber No. 2 grade

1.4 References

American Society for Testing and Materials. 2014. D 245. Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014. D 1990. Establishing allowable properties for visually-graded dimension lumber from in-grade tests of full-size specimens. ASTM International, West Conshohocken, PA.

Antony F, Schimleck LR, Daniels RF, Clark A, Borders BE, Kane MB, Burkhart HE. 2015. Whole-tree bark and wood properties of loblolly pine from intensively managed plantations. Forest Science 61(1):55–66.

Berg WG, Cummin JH, Foreman J, and Fry HL. 1907. Strength of bridge and trestle timbers. *In*: Proceedings of annual convention of the American International Association of Railway Superintendents of Bridges and Buildings; 1895 October, New Orleans, LA, 14-63 pp.

Betts HS. 1915. Discussion of the Proposed Forest Service Rules for Grading the Strength of Southern Pine Structural Timbers. 18th Annual Meeting of the American Society for Testing and Material Proceedings, 15:1pp.

Brown LS, De Visser DA, TuveyA RS, and Rozek AK. 1997. Mechanically graded lumber: A grading agency perspective. Wood Design Focus 8(2):3-7.

Cline M, and Heim AL. 1912. Tests of Structural Timbers. U. S. Department of Agriculture, Forest Service Bulletin No. 108, Forest Products Laboratory Series, 123 p.

Dahalen J, Jones PD, Seale RD, and Shmulsky R. 2014. Sorting lumber by pith and its effect on stiffness and strength in southern pine No. 2 2 x 4 lumber. Wood and Fiber Science 46(2):186-194.

Gaby LI. 1985. Southern pines: loblolly pine (*Pinus taeda* L.), longleaf pine (*Pinus palustris* Mill.), shortleaf pine (*Pinus echinata* Mill.), slash pine (*Pinus elliottii* Engelm.). USDA Forest Service. Forest Products Laboratory. FS-256 Washington, DC. 10 pp.

Green DW, Evans JW. 2001. Evolution of Standardized Procedures for Adjusting Lumber Properties for Change in Moisture Content. USDA Forest Service. Forest Products Laboratory. FPL-GTR-127. Madison, WI. 50 p.

Green DW, Kretschrnann DE. 1991. Lumber Property Relationships for Engineering Design Standards. Wood and Fiber Science 23(3):436–456.

Green DW, Ross RJ, Mcdonald KA. 1994. Production of hardwood machine stress rated lumber. *In*: Proceedings of 9th International symposium on nondestructive testing of wood. Forest Products Society, Madison, pp. 141–150.

Ivory EP, White DG and Upson AT. 1923. Standard grading specifications for yard lumber. USDA, Department Circular 296, Washington, DC, 103 p.

Kretschmann DE, Evans JW, Brown L. 2010. Stress Grades and Design Properties for Lumber, Round Timber and Ties. Pages 7-1-7-16. In: Ross RJ ed., Wood Handbook. USDA Forest Service. Forest Products Laboratory. FPL-GTR-190. Madison, WI.

Mackay JFG. 1981. Developing new standard on recommended procedures for use and calibration of portable moisture meters. In: Proceedings annual meeting-Western Dry Kiln Clubs. 1981.

Madsen B and Nielsen LF. 1992. Structural behavior of timber. Timer Engineering Ltd., North Vancouver, Britsh Columbia, Canada.

Montero M, Mateo R, Íñiguez-González G, Martitegui A, Hermoso E, Esteban M. 2011. Visual grading of large cross section structural timber of *Pinus sylvestris* L . according to UNE 56544 : 2007 standard. Pages 1-6. in SHATIS'11 Int Conf Struct Heal Assess Timber Struct, June 2011, Lisbon, Portugal.

Newlin JA and Johnson RPS. 1923. Basic Grading Rules and Working Stresses for Structural Timbers. Circular 295, U. S. Department of Agriculture Forest Service, Forest Products Lab, Madison, WI.

Ross RJ. 2015. Nondestructive Evaluation of Wood: Second Edition. USDA Forest Service. Forest Products Laboratory. FPL-GTR-238. Madison, WI. 176 p.

Shelley, B.E. 1989. Sampling procesures used in the in-grade lumber testing program. In: Green, DW, Shelley BE, Vokey HP. eds. In-grade testing of structural lumber. Proceedings 47363. Madison, WI: Forest Products Society: pp. 15–26.

Southern Pine Inspection Bureau (SPIB) (2010) Notice. Application: Visually graded structural dimension lumber, 2" – 4" thick graded under the voluntary product standard 20 national grading rule. July 28, 2010. http://www.spib.org/DesignNotice.pdf (25 May 2017).

Winistorfer SG and Theilen RD. 1997, Machine-Graded lumber-Design Implications. Wood and Design Focus 4(3):3-7.

Zobel B. 1984. The changing quality of the world wood supply. Wood Science and Technology 18(1):1-17.

Zobel BJ, Van Buijtenen JP. 1989. Wood variation: its causes and control. Berlin, Spirnger-Verlag, 418p.

CHAPTER II

SAMPLE PREPARATION AND TESTING

2.1 Sampling method

It was not the intention of this research to develop design values of southern pine dimension lumber but to evaluate the material commercially sold in the southern U.S. region. The intention was also to collect global sample of No. 2 2 × 4, 2 × 6, 2 × 8, and 2 × 10 for testing in bending from 15 of the original 18 regions spread across the South (Figure 2.1). The sample size was developed based on production weighted by region. The region designation associated with each piece is based on the mill location where it was produced.

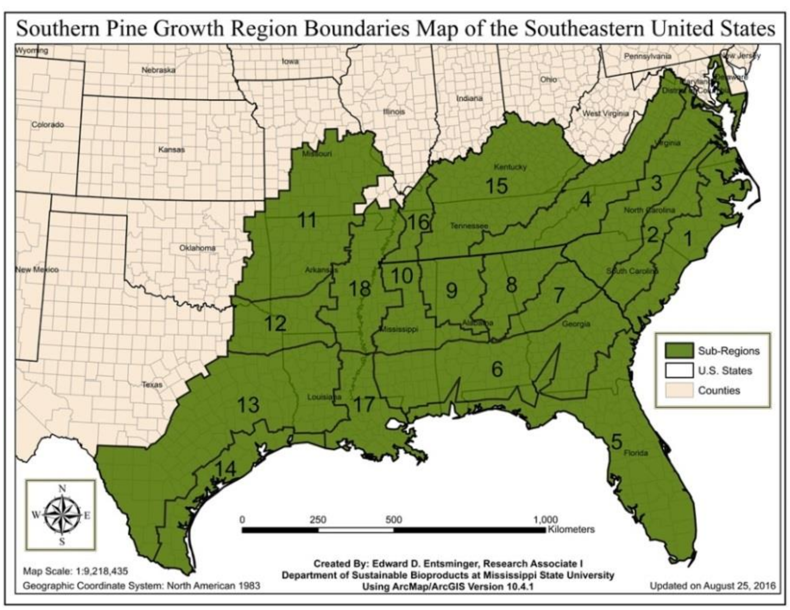


Figure 2.1 Map of southern pine growth regions of southern pine (Shelley 1989)

Number 2 lumber was selected for this study because it is the most widely produced southern pine grade. The lumber obtained for this study was manufactured at commercial sawmills that have lumber graded under the auspices of either Southern Pine Inspection Bureau (SPIB) or Timber Products Inspection (TP).

The originating mills were tracked and tabulated so that all the regions were sampled. Before any material was gathered, a list was created with mill number and corresponding region for SPIB and TP member mill. This list was then sorted from smallest to largest mill number in order to create a master mill-region list for rapid identification of region when seeking lumber from various yards.

For each region, potential lumber distribution sites were identified in advance using Google. For example, a map of Roanoke, Virginia showing the local lumber yards is shown in Figure 2.2. A truck with a trailer was then driven to the area and a number of different lumber yards were visited until a sufficient number of specimens have been acquired or until the trailer was full to capacity.

Figure 2.2 Illustration of lumber yards in Roanoke (located in Region 3) area

At each lumber yard, the potential for obtaining 2 × 4, 2 × 6, 2 × 8 and 2 × 10 was determined. In many cases it was possible to get all sizes at a particular yard. The length of the pieces ranged from 2.4 to 4.9 m depending on the dimension stock width. In cases where a new bundle was broken open the top course of material was removed. Most bundles in a lumber yard, however, were already open so the top course was removed. For each bundle or lumber package, the mill number was identified and checked against the master mill-region list to determine if candidate material was still needed for that region. At each lumber yard, candidate material may be from a number of different regions. If additional lumber packages from that yard contained lumber from a different mills or regions, then the process was repeated and more candidate stock was obtained. A running tally was maintained for each region in order to identify what volume of material was still needed. This process was repeated at a number of different yards until the trailer was full to capacity. An example of the master list is given in Table 2.1.

Table 2.1 Example of a master list of No. 2 material from given mills and regions

Region	Sawmill	Agency	2 × 4	2 × 6	2 × 8	2 × 10
	025	TP			4	13
1	243	SPIB			25	13
	555	TP		25	26	13
2	832	TP	25	33	21	13
3	123	TP	25		25	13
	154	SPIB				13
5	143J	SPIB			25	
	063	TP	22	25	49	28
6	334	TP	25	27		15
	67	SPIB		24	23	13
:	:	:	:	:	:	:

2.2 Marking and labeling of specimens

All specimens were labeled with a unique number. The number was applied to each end, each with a different colored (green and blue) permanent marker for future reference (Figure 2.3). The starting number of the label indicated its width. The remaining three numbers represented the specimen’s number. The 2 × 4 were be labeled with 4000’s, 2 × 6 with 6000’s, 2 × 8 with 8000’s and 2 × 10 with 1000’s. In addition to these marks, each piece received a bar code with same number for a better control of identification throughout.

Figure 2.3 Labeling methods for specimens

2.3 Specimen preparation

Figure 2.4 shows the layout for gathering specimen data. For better control of the material, the green label was referenced as the left end and blue label as the right end of each piece. The grade stamp on each piece was located on the top of the piece. Stamp orientation was then used as a reference to randomly assign tension versus compression edges during the subsequent static testing. In addition to serving as a reference point, the grade stamp also provided agency and mill number information. This configuration helped to keep pieces in the same random positions for all the tests, to provide a consistent means of following the specimens through the tests, and to locate characteristics for subsequent data collection.

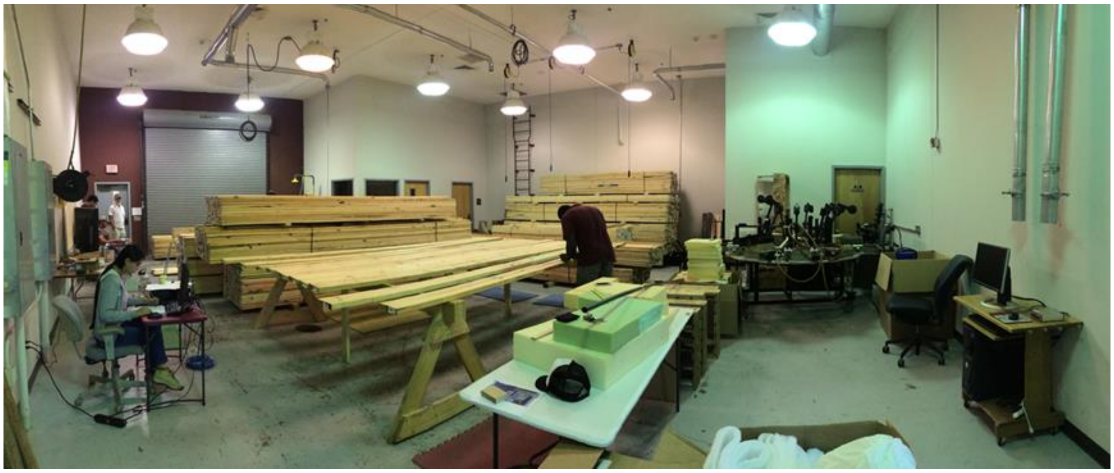


Figure 2.4 Layout for gathering specimen data

The number of rings per inch (RPI) and percentage of latewood (LW) for each piece were collected according to SPIB rules (SPIB 2014). For a more precise estimation, RPI and LW were measured at each end (green and blue) of each piece, and an average value for RPI and percent latewood was calculated and recorded for each piece.

The RPI was calculated by counting the total of number of rings on the cross section. If it is a tangential specimen it was divided by the thickness, and divided by the width if the specimen was radial. In each case, the line of measurement was taken perpendicular (radially) to the annual (tangential) growth rings.

For LW measurement, a 1 x 1 in. dot screen containing a total of 64 dots may be used as a template. The dots that touch the latewood (darker rings) are counted and then the LW is calculated by the sum of dots divided by the total of dots on the grid (Figure 2.5).

Figure 2.5 Estimation of percent of latewood

In order to evaluate the presence of pith, the pieces were inspected on all six faces. If pith appeared on any face of the piece was considered as containing pith (Table 2.2). All pieces were stored indoors in a humidity controlled environment (conditioned to 12% equilibrium moisture content) during the evaluation process. The sample counts, by width and length are presented. Packages of lumber were stored indoors for approximately 90 days during the evaluation and testing process. This process helped assure that each piece achieved equal moisture content. Throughout the evaluation process, a hygrometer was used to verify and record the conditions of indoor environment (temperature and relative humidity).

Once the material was accumulated, all pieces were visually re-graded by a certified grader from either SPIB or TP. This process determined the true grades for the various pieces and verified that the material was actually No. 2 grade (on-grade).

Table 2.2 Sample grouping according to cross-section dimension

Groups	2 × 4	2 × 6	2 × 8	2 × 10
Sample size	363	388	291	181
Length (m)	2.4; 3.0; 3.7; 4.2; 4.9	3.0; 3.7; 4.2; 4.9; 7.3	3.7; 4.2; 4.9	4.2; 4.9
Test span (m)	1.5	2.38	3.1	4.0

a random number from 0 to 100 was generated to determine the placement of the testing span. This process reduced bias and randomized the location of grade characteristics with respect to the position of the load heads. To ensure that the specimen had enough overhang at both ends during testing, an additional 6 in. of overhang was added to each end (green and blue end) factored in to the lengthwise position of the test span. For example, the random number 0 was equal to 6 in. from green end, and if the random number is 100 the test span was 6 in. from the blue end. The remainder of length (portion available for positioning) within the test span was the total specimen length, minus testing span length, plus two times the target overhang (Equation 2.1).

$$L_{pp} = L_t - (L_s + 2 \cdot overhang) \tag{2.1}$$

Where:

L_{pp} = Lengthwise positioning proportion;

L_t = total piece length

L_s = test span length

The distance from the green (color referenced) end was calculated as the proportion available for lengthwise positioning multiplied by the random number plus 6-in. (overhang) (Equation 2.2):

$$Position\ from\ green\ end = \left(\left(\frac{random\ number}{100}\right) \times L_{pp}\right) + \ (1\ \times overhang) \quad (2.2)$$

Templates cut to the length of the test span (one for each cross section / span length) were used to mark the span, and load head placement using indelible ink. The green end was used as a starting point of positioning the template (Figure 2.6).

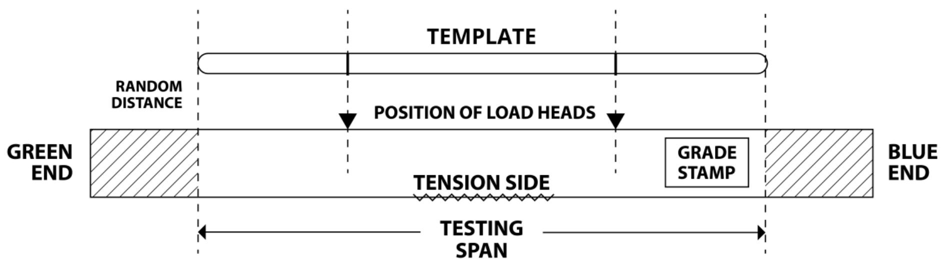


Figure 2.6 Illustration of specimen labeling and positioning

2.4 Code and grading characteristics between load heads

The grade controlling characteristics were divided into two categories, strength reducing characteristics (SRC), and grade reducing characteristics (GRC). These characteristics can be knots or others types of defects that are presented in ASTM D 4761 (ASTM 2014b). The grader specified the SRC and GRC and subsequently assigned a grade to each piece. In many cases, it is not feasible to code all characteristics on each piece. Knowing that most of the time, failure of each piece will commence between the load heads in the section of maximum moment, it is recommended to code the controlling characteristics indicated by the grader and, if possible, to code the characteristics within the zone of maximum moment. The SRC and GRC, regardless of location and all knots within the constant moment zone load points should be measured and coded according to ASTM D 4761 (ASTM 2014b) (Figures 2.7 and 2.8).

When knots are being coded according ASTM and SPIB rules, only one measurement of XY is taken. However, in this study, two measurements of X and Y were taken, one along the length (XL or YL) and another along the width (XW or YW) of the piece. The measurements of A, B, X and Y were taken in sixteenths of an inch and distance from green and distance from tension were measured in inches.

Figure 2.7 shows 10 different types of knots that can cause specimen failure. This grading system is more detailed in comparisson to the three basic knot types given in Figure 2.8 (narrow face knot, wide face center knot, and wide face edge knot), since it has more types of defects. With these measurements it was possible to calculate the knot size. Figure 2.8 is a broader grading system, it converts 10 different types of knots in basically three knot types (edge of wide face knot, narrow face knot and center-line knot). With this information, researchers and engineers are able to know each knot's type, size, and location. Based on the information presented in Figure 2.8, codes were generated according to growth characteristics on each piece. The codes generated using Figure 2.8 were used to calculate the strength ratio of the pieces. The distance from tension face and distance from green end were recorded for each coded knot.

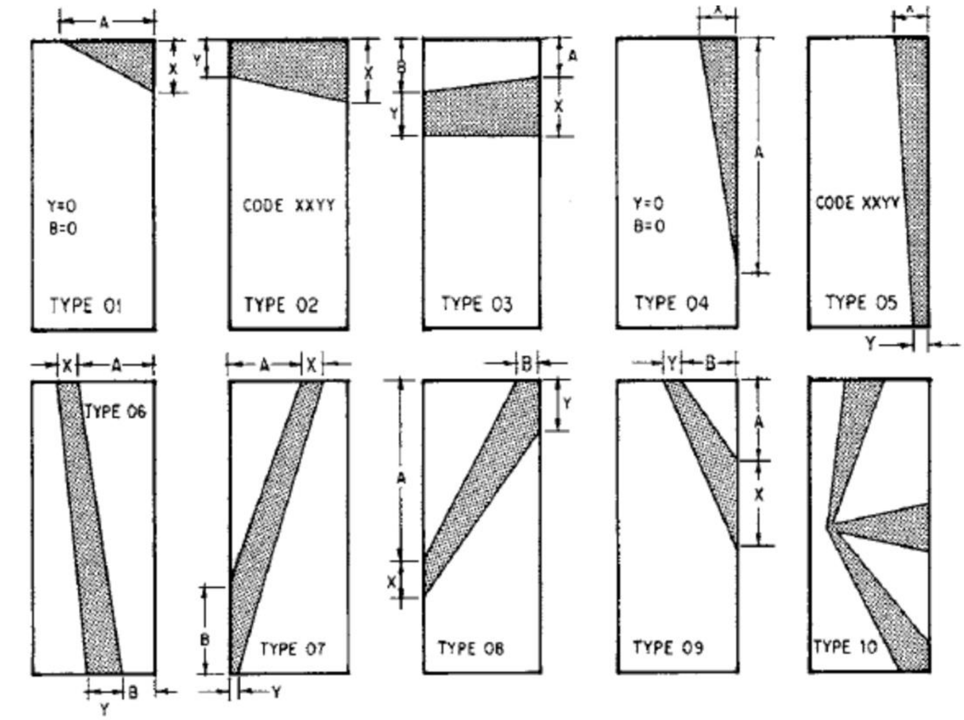


Figure 2.7 Knot measurements according to ASTM D 4761 (ASTM 2014b)

TABLE X1.1 Recording Scheme to Describe Characteristics in Stress-Graded Lumber

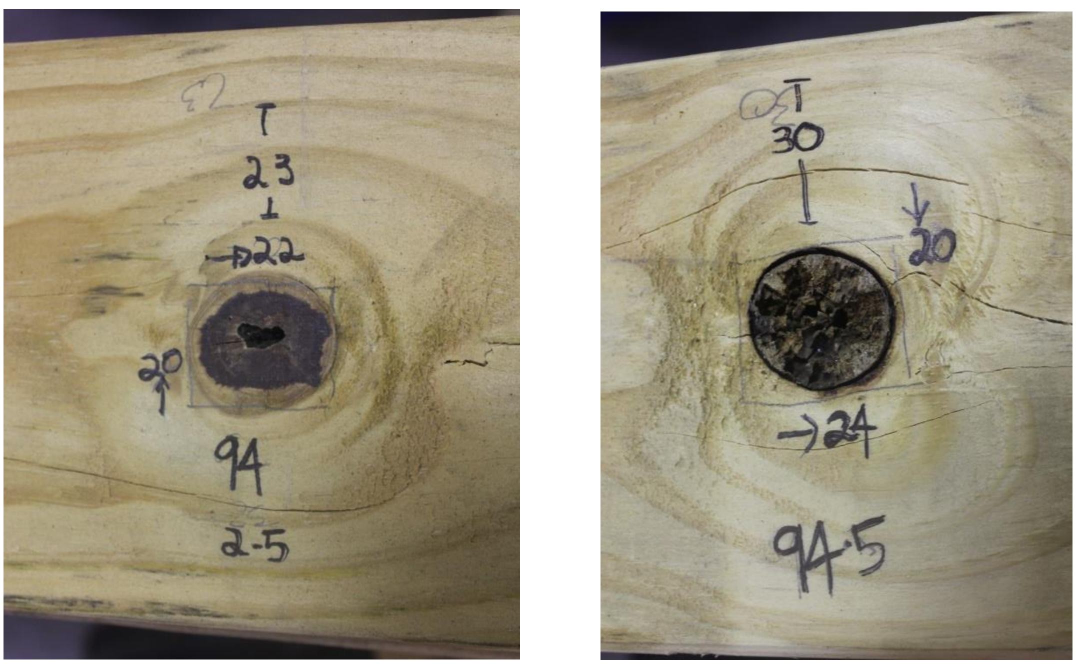
Characteristic	X	Y	Characteristic	X	Y
Narrow face or spike knot intergrown	11		Splits	44	01 for very short 02 for short 03 for medium 04 for long
Narrow face or spike knot encased	12	displacement, %			
Narrow face or spike knot unsound	13				
Wide face knot, center line intergrown	14	knot size (nearest 1/16 in.)			
Wide face knot, center line encased	15	for example, 08 for ½-in. knot.	Skip	45	01 for light 02 for medium 03 for heavy
Wide face knot, center line unsound	16				
Wide face knot, at edge intergrown	17				
Wide face knot, at edge encased	18	knot size (nearest 1/16 in.)	Warp	46	00 for ½ of medium 01 for light 02 for medium 03 for heavy
Wide face knot, at edge unsound	19				
Knots, not well spaced, or combinations	20	cross section, %			
Hole	21	size as knot (nearest 1/16 in.)	Mechanical damage	47	percent
			Crossbreak	49	displacement, %
Pin holes	22	cross section, %			
Grub or teredo holes	23		Saw cut	50	01 saw cut through edge 02 all other saw cuts
Speck	31		Slope of grain	51	run of slope[A]
Honeycomb	32	cross section, %			
Unsound wood or peck	33		Wane	52	first digit is number of fourths of width; second is fourths of thickness
Distorted grain, knot cluster, or burl	34	displacement, %			
Heart stain	35	displacement, %	Falling breaks	53	01, ⅓ or less of width 02, ⅓ to ⅔ of width 03, ⅔ or more of width
Pitch or bark pockets	41	01 for very small 02 for small 03 for medium 04 for large 15 for very large	Brash failure (not defect related)	54	
			Compression wood	55	
			Coarse grain or exceptionally light weight	56	
Shake	42	01 for light, not through 02 for medium, not through 03 for others, not through 11 for light, through 12 for medium, through 13 for others, through	Local grain deviation on wide face (failure initiated in locally severe grain deviation)	60	run of slope (use 00 if less than 1 in 1)[A]
			Local grain deviation on narrow face (failure initiated in locally severe grain deviation)	70	run of slope as above
Seasoning or roller check	43	01 for surface 02 for small, through 03 for medium, through 04 for large, through	Failure at the point where the sticker crossed the specimen in the package during kiln-drying[B]	99	moisture content at point failure

[A] Expressed in inches, corresponds to a 1-in. rise.
[B] Must be used in conjunction with another characteristic.

Figure 2.8 Characteristics in stress-graded lumber ASTM D 4761 (ASTM 2014b)

Figure 2.9 shows an example of coding for knot type 03. A characteristic of a type 03 knot is that the knot is in the middle of the width of the piece with wood on each side between the knot and the edge of the piece. A type 03 knot may or may not go through to the other side of the specimen. For this type of knot, measurements of X and A on the face of the piece are needed, and, if the knot goes all the way through the piece, Y and B are measured as shown for a Type 3 knot in Figure 2.9.

Figure 2.9a shows X and A face of the specimen, where XL is 22/16 in and XW 20/16 in, A is 23/16, 94.5 in is distance from green, and 2.5 in is distance from tension. Figure 2.9b shows face 2 of the specimen, where 20/16 in is YL, 20/16 in is YW and 30/16 in is B.



(a) (b)

Figure 2.9 Example of grade characteristic coding a) Face 1. Measurements of XL, XW, A in sixteenths of an inch, and distance from green and distance from tensionedgein inches; b) Face 2. Measurements of YL, YW and B

2.5 Mechanical testing

The dimensions, weight, specific gravity, and moisture content (MC) were measured. The edgewise bending test was conducted according to ASTM D 198 (ASTM 2014c) via four-point loading, and the span ratio was 17 to 1. The rate of loading was in accordance with ASTM D 4761 (ASTM 2014b). The deflection at mid-span was measured by a deflectometer to determine MOE. Modulus of rupture (MOR) was calculated from the maximum load (Figure 2.10). A series of adjustments were done in order to compare the results found in this research to previous studies and to the design values, which are published at 15% MC (ASTM D 1990 2014d; Evans et al. 2001). The allowable design bending strength (F_b) was calculated using the nonparametric 5th percentile at 75% confidence per ASTM D 2915 (ASTM 2014a).

Figure 2.10 Static bending test setup

2.6 References

American Society for Testing and Materials. 2014a. D 2915. Standard practice for sampling and data-analysis for structural wood and wood-based products.. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014b. D 4761. Standard test methods for mechanical properties of lumber and wood-base structural material. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014c. D 198. Standard test methods of static tests of lumber in structural sizes. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014d. D 1990. Standard practice for establishing allowable properties for visually-graded dimension lumber from in-grade tests of full-size specimens. ASTM International, West Conshohocken, PA.

Southern Pine Inspection Bureau – SPIB. 2014. Standard grading rules for southern pine lumber. Southern Pine Inspection Bureau. Pensacola, FL.

CHAPTER III

BENDING STRENGTH AND STIFFNESS OF No. 2 GRADE SOUTHERN PINE LUMBER

3.1 Abstract

Southern pine lumber is the most important species group planted and used for lumber products in the southern U.S. The majority of southern pine trees come from managed forests, with relatively short rotations and excellent growth yields. The accelerated growth volume allows trees to have merchantable size in 16-22 years. However, these trees contain a large amount of juvenile wood which can negatively impact the bending properties of lumber. In 2010, the Southern Pine Inspection Bureau (SPIB) began to re-evaluate the mechanical properties of southern pine lumber, which resulted in changes in design values. The objective of this study was to summarize growth characteristics and bending properties of No. 2 grade 2 × 2 × 4 (n = 363), 2 × 2 × 6 (n = 388), 2 × 2 × 8 (n = 291), and 2 × 2 × 10 (n = 181) production weighted sample collected across the geographical growing range. Overall, 34.5% of the sample contained pith and averaged 4.6 rings per inch (RPI) and 43.8% latewood (LW) and met or exceeded the strength requirements for southern pine No. 2 grade. The sample average specific gravity (SG), modulus of elasticity (MOE), and modulus of rupture (MOR) were 0.54, 10.1 GPa, and 41.7 MPa, respectively. For allowable design bending strength (F_b), the study shows a trend that as lumber size increases (2 × 2 × 4, 2 × 2 × 6, 2 × 2 × 8, and

2 × 2 × 10) the F_b decreases (11.2, 9.2, 8.1, and 7.1 MPa). The F_b values determined herein exceeded the new published design value and also met the previous (SPIB) design values. The results suggest that timber resource quality has been increasing since the housing crisis of 2008-2010.

3.2 Introduction

Southern pine is the most commercially important species group used for lumber and the majority of this lumber available in the market is visually graded (Gaby 1985). Limits for strength reducing characteristics such as maximum sizes and locations of knots, slope of grain, and minimum density permitted for a specific grade are the primary bases for visual grading of structural lumber. The visual grading process involves examination of the four faces of each piece and evaluation of the major characteristic that determine the grade. Due to high production volumes of lumber, evaluation must be done quickly. Usually, the grading process is completed in two to three seconds. A variation of 5% is acceptable among visually graded lumber packages to account for differences among inspectors. If a lumber package contains less than 95% of the pieces at or above stated grade, re-examination is required. The advantages of visual grading are: no need for significant additional tools or capital equipment; fast and ideal method for small sawmills and local markets; rapid sorting; and wide market acceptability. However, it is conservative, and it can be labor intensive and the visual grade might not reflect the actual strength and stiffness of each piece (Kretschmann and Hernandez 2006).

Classification of lumber by visual grading is based on human inspection or by automated imaging with cameras combined with laser-based systems along with sensors and sometimes X-rays to feed computer systems with data that are able to identify various characteristics (Bharati et al. 2003). Regardless of the system employed, in visual grading, the major strength reducing characteristic must be quickly identified and assessed. There are many characteristics that affect the mechanical properties of lumber, but only the most significant characteristics are considered. In southern pine lumber the most common strength reducing characteristics are knots.

During the 1990s and early 2000s, SPIB conducted nondestructive tests on 400 specimens per year in the No. 2 2 × 2 × 4 to assess potential resources changes (Kretschmann et al. 1999). In 2010, SPIB conducted a study to re-evaluate mechanical properties as follow up to the In-Grade program of the late 1980s. In 2011, an In-Grade resource monitoring program noted that the mechanical properties of southern yellow pine dimension lumber were lower than those published in the then-current edition of the National Design Specification (NDS). A full In-grade test program was initiated, the change was shown to be non-trivial, and thus the design values for southern pine were fully investigated and were subsequently changed (SPIB 2012). The results of the tests showed a decrease in stiffness and strength in the No. 2 2 × 2 × 4 lumber. Further, tests were performed in other widths (2 × 2 × 8 and 2 × 2 × 10) and grades (Select Structural and No. 2) and ultimately, this evaluation program resulted in changes in southern pine design values (ALSC 2013). Table 3.1 shows the changes in design values for southern pine dimensional lumber.

Table 3.1 Previous and new design values for southern pine No. 2 grade lumber (AFPA 2005; ALSC 2013)

Lumber Size	Previous design value (2012 and prior)		New design value (2013 and after)	
	MOE (GPa)	F_b (MPa)	MOE (GPa)	F_b (MPa)
2 × 2 × 4	11.0	10.3	9.7	7.6
2 × 2 × 6		8.6		6.9
2 × 2 × 8		8.3		5.5
2 × 2 × 10		7.2		5.2

A probable reason for the change in strength and stiffness values was due to an extraordinary amount of juvenile and/or low-quality trees entering the market from large land-holding companies trying to stay afloat during the 2010 era (Kretschmann et al. 2010). Essentially, during the housing crisis of 2008-2010, it appears that unusually low value trees were processed. Since the housing crisis, monitoring of the timber resource has continued and mechanical properties have indicated a steady recovery and rebound. It was noted at the time that a much greater proportion of the material being tested had a high incidence of combination of knots and high frequencies of other grade controlling characteristics such as slope of grain.

This situation called for further scientific investigation into potential improvements that could be made by refining the visual characteristics that are used to assign lumber grades. The objectives of this study were to: (1) summarize the nature of specific characteristics of 2 × 2 × 4, 2 × 2 × 6, 2 × 2 × 8, and 2 × 2 × 10 southern pine lumber No. 2 grade (presence of pith, number of rings per inch and percentage of latewood); (2) determine bending strength and stiffness; (3) determine the statistical distribution of specific gravity (SG), modulus of elasticity (MOE) and modulus of rupture

(MOR) data; (4) compare these results of MOE and allowable design bending strength (F_b) with previous and current design values.

3.3 Material and methods

3.3.1 Test material

A production weighted sample of southern pine No. 2 grade lumber 2 × 2 × 4 (n = 363), 2 × 2 × 6 (n = 388), 2 × 2 × 8 (n = 291), and 2 × 10 (n = 181) was collected from 15 of the original 18 regions spread across the southern U.S. Specimens were obtained from commercial sawmills via the stream of commerce (i.e. building supplies across the southern U.S.). The lumber was graded under the auspices of Southern Pine Inspection Bureau (SPIB) or Timber Products Inspection (TP). No. 2 grade was chosen because it accounts for the largest volume production of pine (SFPA 2005). The specimens were transported to the testing laboratory and re-graded by a certified grader from either SPIB or TP to ensure that the specimens were No. 2 grade (on-grade).

3.3.2 Specimen preparation and testing

Data collected on each specimen included dimensions, weight, SG, moisture content (MC), presence of pith, number of rings per inch (RPI) and percentage of latewood (LW). All six faces of the specimens were inspected in order to evaluate the presence of pith. If pith appeared on either half of the length it was considered as containing pith. The RPI and LW were measured at each end of each piece according to Southern Pine Grading Rules (SPIB 2014), and an average value for RPI and LW was calculated and recorded for each piece. The average MC of the lumber sample was 11.1% with a range from 6% to 17%.

The edgewise bending test setup adhered to the specifications of ASTM D 198 (2014c) via four-point loading and the span-to-depth ratio was 17 to 1. The tension face and the grade characteristics were randomly selected without respect to positioning in the test failure according to ASTM D 4761 (ASTM 2014b). MOE was determined using a deflectometer (at mid span) synchronized with load in the elastic range and MOR was determined from the maximum load.

A series of adjustments were needed in order to compare the results to previous studies and to the design values which are published at 15% MC (Evans et al. 2001; ASTM D 1990 2014d). The F_b was calculated using the nonparametric 5^{th} percentile at 75% confidence per ASTM D 2915 (ASTM 2014a).

3.3.3 Statistical analysis

The statistical analysis and associated graphics were performed using SAS version 9.4 (SAS 2013) according to ASTM D 2915 (2014a). The mean, median and coefficients of variation (COV) were calculated for the RPI, LW, SG, MOE and MOR. Statistically significant differences were found among widths in RPI, LW, SG, MOE and MOR at $\alpha = 0.05$ level using the PROC GLM function in SAS. The SG, MOE and MOR data were tested for goodness of fit using the Cramer-van Mises test for the normal, lognormal and Weibull distributions selected by PROC UNIVARIATE and the histogram option in SAS.

3.4 Results and discussion

Table 3.2 summarizes the basic characteristics of the specimens. Over one third (34.6%) of the specimens contained pith. The average RPI for the sample was 4.6;

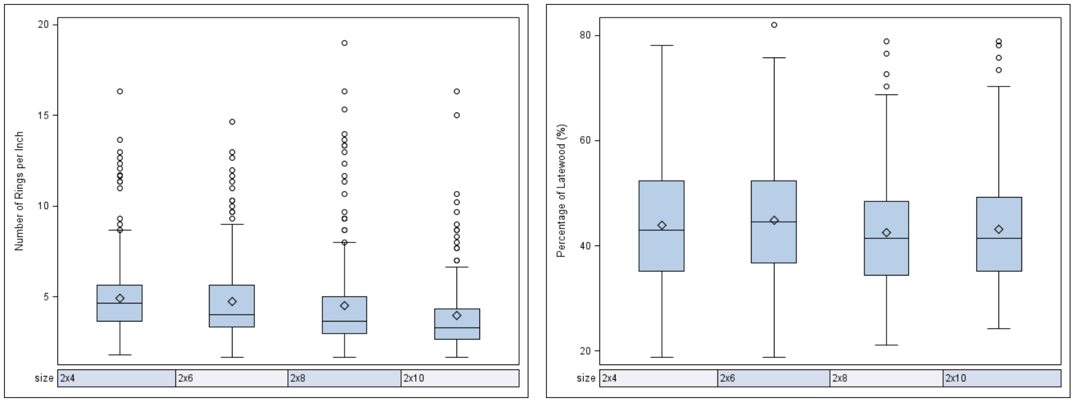
the average LW was nearly 50% percent. The 2 × 10 size had the highest number of specimens that contained pith (54.7%), and 2 × 4 specimens had the least number of specimens that contained pith (21.5%). The results suggest that as lumber size (width) increases (2 × 4, 2 × 6, 2 × 8 and 2 × 10) the number of specimens that contained pith increases (21.5, 30.7, 43.6, and 54.7%, respectively).

Table 3.2 Summary statistics for number of rings per inch (RPI) and percentage of latewood (LW) for No. 2 grade southern pine lumber by size

Size	N	Pith (%)	Rings per inch			Latewood (%)		
			Mean[1]	Median	COV (%)	Mean[1]	Median	COV (%)
2 × 4	363	21.5	4.9[a]	4.7	42.3	44.0[ab]	43.0	26.7
2 × 6	388	30.7	4.8[ab]	4.0	46.7	45.0[a]	44.5	25.0
2 × 8	291	43.6	4.5[b]	3.7	57.0	42.5[b]	41.1	25.0
2 × 10	181	54.7	4.0[c]	3.2	55.3	43.1[ab]	41.1	25.1
Overall	1223	34.6	4.6	4.0	49.3	43.8	43.0	25.7

[1]Significant difference in SG, MOE and MOR between sizes are indicated by different upper case letters at $\alpha = 0.05$

There was a statistically significant difference found in RPI ($p < 0.0001$) within sizes (Figure 3.1a). The 2 × 10 size was statistically lower in RPI (4.0), and 2 × 4 had the highest RPI mean value (4.9). There was a statistically significant difference found in LW ($p = 0.0390$) within sizes (Figure 3.1b). For LW, 2 × 8 specimens were statistically lower in MOR value (42.5%), while 2 × 6 had the highest LW mean value (45.0%).



(a) (b)

Figure 3.1 Boxplots distribution of (a) number of rings per inch; (b) percentage of latewood (%)

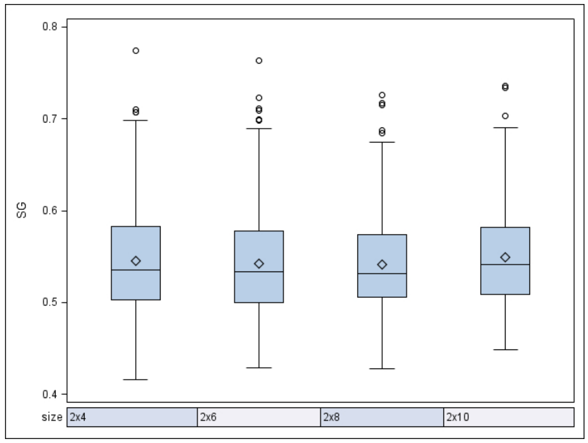
The summary statistics for SG, MOE and MOR are presented in Table 3.3. The SG mean value for the sample was 0.54. The MOE mean value was 10.1 GPa, and it ranged from 9.7 to 10.5 GPa. The MOR mean value was 41.7 MPa, with a range from 39.2 to 49.7 MPa. The F_b values for 2 × 4, 2 × 6, 2 × 8, and 2 × 10 lumber were 11.2, 9.2, 8.1, and 7.1 MPa, respectively.

Table 3.3 Summary statistics for specific gravity (SG), modulus of elasticity (MOE), modulus of rupture (MOR) and bending strength (F_b) for No. 2 grade southern pine lumber by size

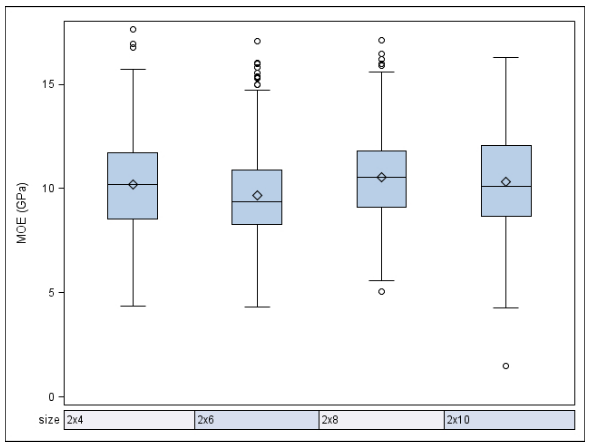
Size	Specific Gravity			MOE (GPa)			MOR (MPa)			F_b[4] (MPa)
	Mean[1]	Median	COV (%)	Mean[2]	Median	COV (%)	Mean[3]	Median	COV (%)	
2 × 4	0.55^{A}	0.54	11.4	10.2^{Bb}	10.2	23.9	51.1^{A}	49.7	34.3	11.2^{c}
2 × 6	0.54^{A}	0.53	10.9	9.7^{Cb}	9.3	22.7	41.6^{B}	40.4	37.8	9.2^{c}
2 × 8	0.54^{A}	0.53	10.0	10.5^{Aa}	10.5	20.6	39.0^{C}	37.5	33.2	8.1^{c}
2 × 10	0.55^{A}	0.53	10.5	10.3^{Aba}	10.1	23.5	39.6^{BC}	39.2	35.3	7.1^{c}
Overall	0.54	0.54	10.0	10.1	10.0	23.0	41.7	41.6	37.3	–

[1]Different letters indicate there is a statistically significant difference within sizes
[2]Different capital letters indicate there is a statistically significant difference within sizes; lower case a indicates MOE value met 2011 design value (11.0 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d); lower case b Indicates MOE value met 2013 design value (9.7 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[3]Different letters indicate there is a statistically significant difference within sizes
[4]Different capital letters indicate there is a statistically significant difference within sizes; lower case c indicates F_b value met 2013 design value for 2 × 4 (7.6 MPa), 2 × 6 (6.9 MPa), 2 × 8 (5.5 MPa), and 2 × 10 (5.2 MPa) rounding to nearest 0.3 MPa ASTM D1990 (2014d)

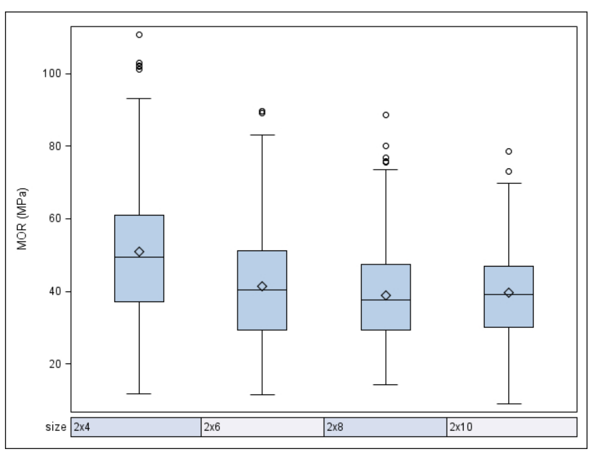
There was no statistically significant difference found in SG ($p = 0.5226$) within sizes (Figure 3.2a). The sample's average MOE was 10.1 GPa, and its' average strength was 41.7 MPa. There were significant differences found in MOE ($p < 0.0001$) and MOR ($p < 0.0001$) by size (Figures 3.2b and 3.2c).



(a)



(b)



(c)

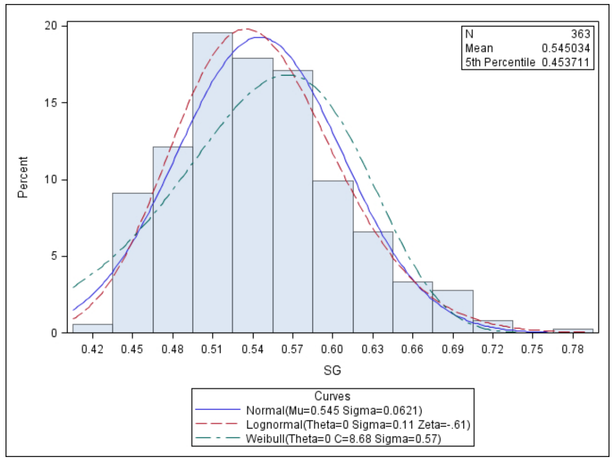
Figure 3.2 Boxplots distribution of (a) specific gravity (SG); (b) modulus of elasticity (MOE); (c) and modulus of rupture (MOR) by size of No. 2 southern pine lumber

For the 2 × 4 size, the goodness of fit test failed to reject the normal distribution for SG ($p = 0.089$), and MOE ($p > 0.250$) data ($p = 0.089$). However, none of the distributions (normal, lognormal, and Weibull) adequately fits MOR data ($p < 0.005$; $p = 0.006$, and $p = 0.022$) (Figure 3.3).

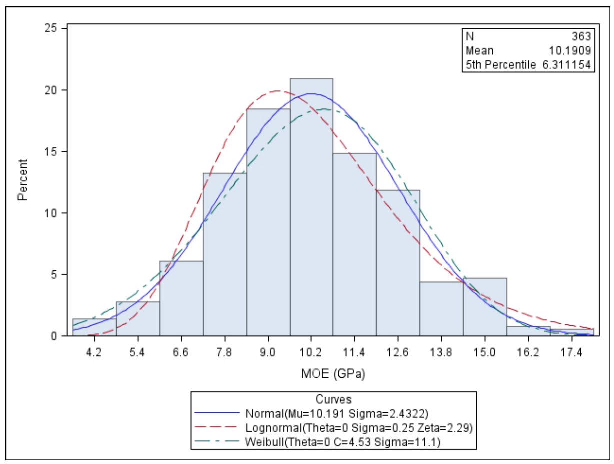
For the 2 × 6 size, the lognormal distribution adequately fits the MOE data ($p = 0.116$). However, none of the distributions tested (normal, lognormal, and Weibull) failed to reject the SG ($p < 0.005$; $p < 0.005$; $p < 0.010$, respectively), and MOR data ($p < 0.010$; $p < 0.010$; $p < 0.045$, respectively) (Figure 3.4).

In 2 × 8, the goodness of fit test failed to reject normal distribution for MOE data ($p > 0.250$). All distributions tested (normal, lognormal, and Weibull) failed to reject the SG data ($p < 0.005$; $p < 0.010$; $p < 0.010$, respectively), and MOR data ($p < 0.005$; $p = 0.046$; $p < 0.010$, respectively) (Figure 3.4).

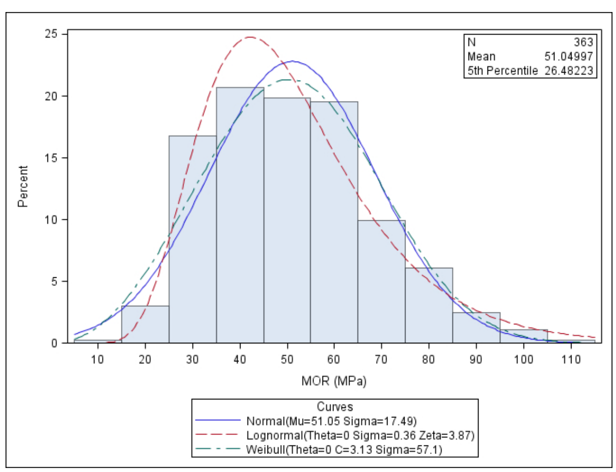
For the 2 × 10 size, the goodness of fit test failed to reject the lognormal distribution for SG data ($p > 0.150$). The normal distribution adequately fits the MOE data ($p = 0.114$). The Weibull distribution fits the MOR data ($p = 0.143$) among all distributions tested (Figure 3.6).



(a)

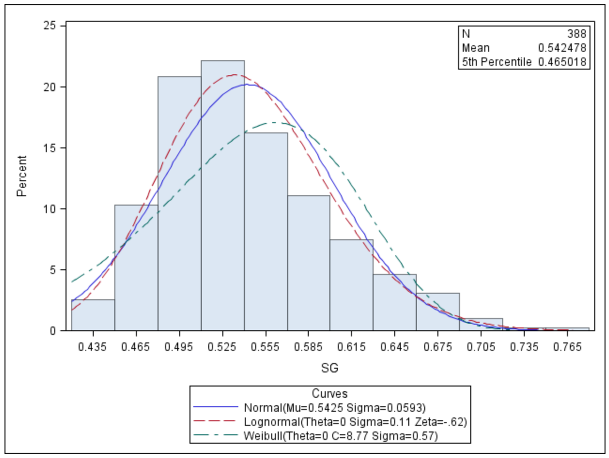


(b)

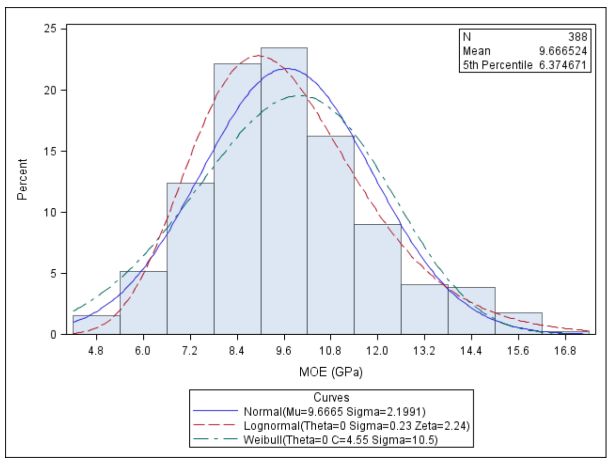


(c)

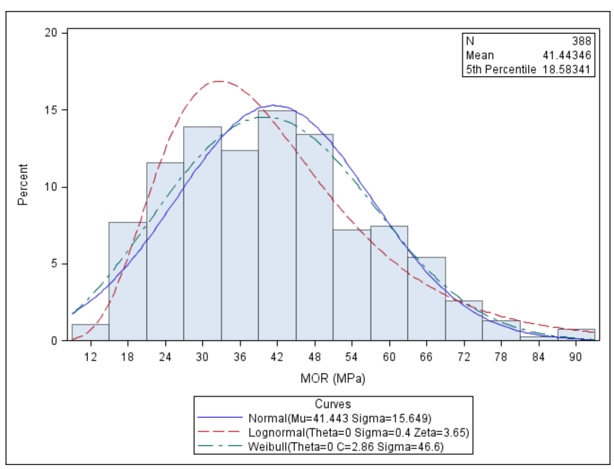
Figure 3.3 Distribution of (a) specific gravity (SG); (b) modulus of elasticity (MOE); (c) and modulus of rupture (MOR) in 2 × 4 of No. 2 southern pine lumber



(a)

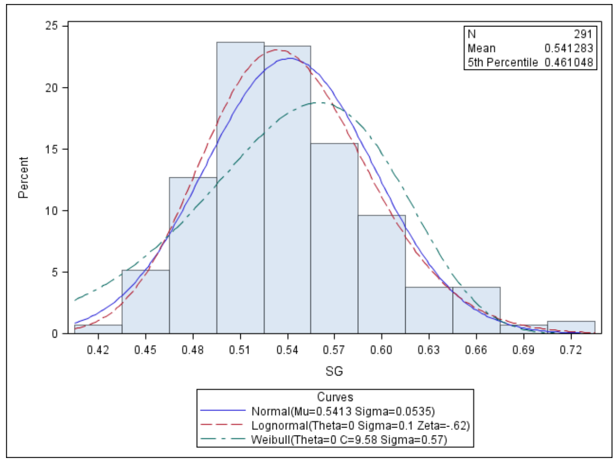


(b)

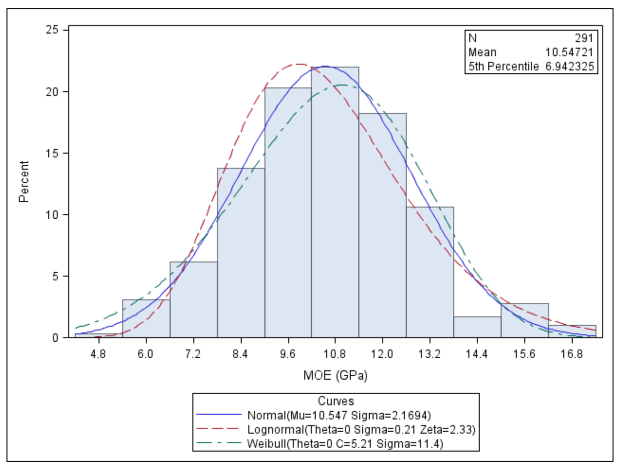


(c)

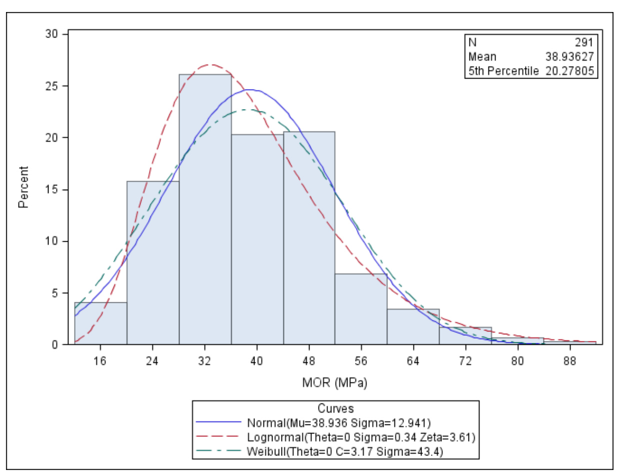
Figure 3.4 Distribution of (a) specific gravity (SG); (b) modulus of elasticity (MOE); (c) and modulus of rupture (MOR) in 2 × 6 of No. 2 southern pine lumber



(a)

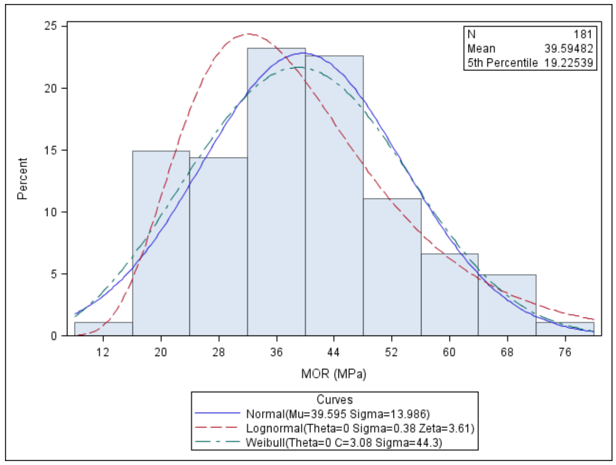


(b)

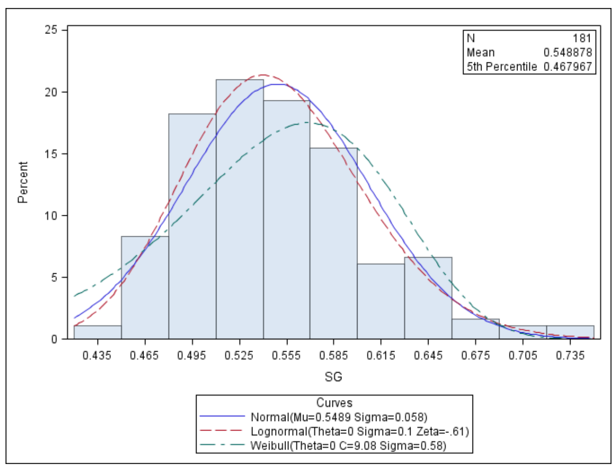


(c)

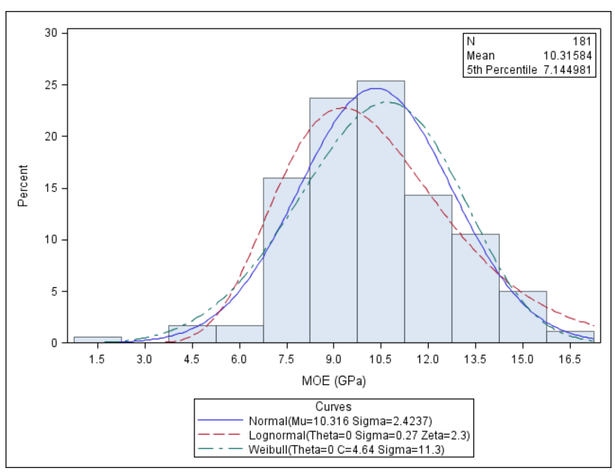
Figure 3.5 Distribution of (a) specific gravity (SG); (b) modulus of elasticity (MOE); (c) and modulus of rupture (MOR) in 2 × 8 of No. 2 southern pine lumber



(a)



(b)



(c)

Figure 3.6 Distribution of (a) specific gravity (SG); (b) modulus of elasticity (MOE); (c) and modulus of rupture (MOR) in 2 × 10 of No. 2 southern pine lumber

According to SPIB rules (2014) No. 2 grade lumber should have approximately 4 or more annual rings per inch on either end of the piece, or at least 1/3 average of latewood (SPIB 2014). All of the specimens met current grading requirements of RPI or LW No. 2 grade.

As noted, the average SG value for the sample was 0.54 with a little variation in the mean by size. The mean SG for all specimens had characteristics of mature wood (Zobel et al. 1972). The sample had a greater SG (0.48) value compared to previous test on southern pine No. 2 grade 2 × 4 lumber (Dahlen et al. 2014); and higher than the SG value (0.50) in the Wood Handbook for loblolly pine when adjusted to 15% MC (FPL 2010).

The MOE mean value of 2 × 4 and 2 × 6 exceeded the new 9.7 GPa design value (ALSC 2013); the 2 × 8 and 2 × 10 MOE mean value was comparable to the previous 11.0 GPa mean design value (AFPA 2005) after rounding according to ASTM D 1990 (2014d), and greater than the new published design value. The overall mean MOE (11.0 GPa) was slightly lower than the mean reported in a previously reported test in southern pine 2 × 4 No. 2 grade (Dahlen et al. 2014). It was also slightly lower than the MOE mean value (10.7 GPa) reported in a prior test in wide dimension southern pine No. 2 grade lumber (Dahlen et al. 2014). The overall MOR was 41.7 MPa, which is slightly higher than the overall MOR (40.7 MPa) value reported by Dahlen et al. (2014) for 2 × 6, 2 × 8, 2 × 10, and 2 × 12 southern pine No. 2 grade; and lower than the MOR value (48.3 MPa) determined in a prior test of southern pine 2 × 4 No. 2 grade (Dahlen et al. 2014).

Fiber bending stress (F_b) values are calculated using the nonparametric 5th percentile and results showed a general trend of F_b decreasing as lumber size increases. The F_b values found herein for 2 × 4 and 2 × 6 (10.3 and 8.6 MPa, respectively) exceeded the previous design value (AFPA 2005), while 2 × 8 and 2 × 10 (8.3, and 7.2 MPa, respectively) met the previous design value after rounding according to ASTM D 1990 (2014d) published by ALSC (2013). This observation suggests that the current timber source that produced the production weighted sample in this study had a relatively higher quality than that used to produce lumber that was sampled in prior tests of No. 2 grade southern pine in 2010 (SPIB 2012). These results show that the continued monitoring of the timber source is recommended, and indicates that the mechanical properties of the contemporary resource are recovering as compared to that sampled during the 2010 housing crisis and economic recession.

3.5 Conclusion

The results present an overall characterization of commercially grown and produced southern pine No. 2 grade, 2 × 4, 2 × 6, 2 × 8, and 2 × 10 lumber sampled from production weighted growing regions.   Overall, 34.6% of the pieces contained pith and as the piece width increases the number of pieces that contained pith also increases. The overall RPI and LW mean values were 4.6 and 43.8%, respectively. The sample met the requirements for RPI and LW for No. 2 grade southern pine lumber (SPIB 2014).

The SG mean value was 0.54 and there were no statistical significant differences among sizes. The MOE for 2 × 4 and 2 × 6 specimens exceeded the new (published) design value, while 2 × 8 and 2 × 10 specimens met the previous (SPIB 2012 and prior) design value. The F_b for all sizes tested met the previous design value. The results obtained in this research suggest that the timber source used herein likely had a higher quality than that which was used to produce the lumber sampled in or around 2010 during the time of the economic recession of approximately 2008-2010.

3.6 References

AFPA. 2005. National design specification (NDS) for wood construction with commentary and supplement: Design values for wood construction 2005 edition. American Forest & Paper Association, Washington, DC.

American Lumber Standards Committee – ALSC. 2013. American Lumber Standard Committee Board of Review: Board of Review Minutes. February 1, 2013. American Lumber Standards Committee, Germantown, MD.

American Society for Testing and Materials. 2014a. D 2915. Standard practice for sampling and data-analysis for structural wood and wood-based products.. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014b. D 4761. Standard test methods for mechanical properties of lumber and wood-base structural material. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014c. D 198. Standard test methods of static tests of lumber in structural sizes. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014d. D 1990. Standard practice for establishing allowable properties for visually-graded dimension lumber from in-grade tests of full-size specimens. ASTM International, West Conshohocken, PA.

Bharati M H, MacGregor J F, Tropper W. 2003. Softwood lumber grading through on-line multivariate image analysis techniques. Industrial and Engineering Chemistry Research 42(21):5345–5353.

Dahlen J, Jones PD, Seale RS, Shmulsky R. 2014. Bending strength and stiffness of wide dimension southern pine No. 2 lumber. European Journal of Wood and Wood Products 72(6):759-768.

FPL. 2010. Wood Handbook – Wood as engineering material. USDA Forest Service. Forest Products Laboratory. FPL-GTR-190. Madison, WI. 508 pp.

Gaby LI. 1985. Southern pines: loblolly pine (Pinus taeda L.), longleaf pine (Pinus palustris Mill.), shortleaf pine (Pinus echinata Mill.), slash pine (Pinus elliottii Engelm.). USDA Forest Service. Forest Products Laboratory. FS-256 Washington, DC. 10 pp.

Kretschmann DE and Hernandez R. 2006. Grading timber and glued structural members. *In*: Walker J. eds, Primary Wood Processing 2nd ed., pp. 339–390.

Kretschmann DE, Evans JW, and Brown L. 1999. Monitoring of visually graded structural lumber. USDA Forest Service. Forest Products Laboratory. FPL-GTR-576. 18 p.

Kretschmann DE, Evans JW, Brown L. 2010. Stress Grades and Design Properties for Lumber, Round Timber and Ties. Pages 7-1-7-16. *In*: Ross RJ ed., Wood Handbook. USDA Forest Service. Forest Products Laboratory. FPL-GTR-190. Madison, WI.

SAS Institute. 2013. SAS® software, version 9.4. The SAS Institute Inc. Cary, NC.

SFPA. 2005. Industry statistics: annual production from 2000 to 2005 (White paper). Southern Pine Forest Products Association, Kenner, La.

Southern Pine Inspection Bureau – SPIB. 2010. Notice. Application: Visually graded structural dimension lumber, 2” – 4” thick graded under the voluntary product standard 20 national grading rule. July 28, 2010. www.spib.org/pdfs/DesignNotice.pdf (25 May 2017).

Southern Pine Inspection Bureau – SPIB. 2014. Standard Grading Rules for Southern Pine Lumber, Southern Pine Inspection Bureau. Pensacola, FL.

SPIB. 2012. Determination of design values for visually graded southern pine dimensional lumber. Pensacola, FL.

Zobel BJ, Kellison RC, Matthias MF, Hatcher AV. 1972. Wood density of the southern pines. Technical Bulletin 208. North Carolina Agricultural Experiment Station. 56 p.

CHAPTER IV

EFFECT OF VISUAL CHARACTERISTICS ON MECHANICAL PROPERTIES OF 2 × 4 AND 2 × 6 SOUTHERN PINE No. 2 LUMBER

4.1 Abstract

Presence of pith, number of rings per inch (RPI) and percentage of latewood (LW) are some of the growth characteristics that can be used to evaluate lumber. Specimens that contain pith are likely to have lower RPI and lower LW, and as consequence may have lower specific gravity, and lower mechanical properties. The objective of this study was to evaluate the effect of presence of pith, RPI, LW on stiffness (modulus of elasticity [MOE]), modulus of rupture (MOR), and allowable design bending strength (F_b) on 2 × 4 and 2 × 6 No. 2 southern pine lumber. Overall, 26.2% of the specimens contained pith. The mean value for RPI was 4.8, and the mean value for LW was nearly 45%. Specimens containing no pith, RPI higher or equal to 4.0, and LW higher or equal to 33.0% were greater in MOE, MOR and F_b values than the other specimens tested. The results show that presence of pith, RPI and LW can potentially be used to improve prediction of lumber properties. In addition, these variables are readily measured in the grading process of lumber.

4.2 Introduction

The use of wood as structural lumber requires a precise grading method to ensure its strength and stiffness values (Blass and Frese 2004). There are two main methods of grading lumber; visual and mechanical grading systems. In the U.S., the most commonly used method is visual grading (Kretschmann and Hernandez 2006). The visual grading system classifies lumber into grades based on characteristics of knots, wane, and warp which decrease lumber value and serviceability (Kimball and Lowery 1967). In addition to these characteristics, pith, annual rings and percent of latewood are growth characteristics used to classify lumber into different grades (Kretschmann 2010).

Visual grading was first developed in or around 1927 and it was based on lumber that contained a large percentage of mature wood from old-growth trees with a high percentage of clear wood. Juvenile wood was not included in the visual grading system (Madsen and Nielsen 1992). To meet the demand for wood products, many landowners supply trees from managed plantations. The growth rate of southern pine is classified as fast-growing in plantations and the success of these plantations is largely due to an extensive silviculture program. Silviculture practices have significant positive impacts on the growth and yield of southern pines (Antony et al. 2015).

Any change in the growth of timber results changes in wood properties and consequently in the quality of wood products (Zobel and Van Buijtenen, 1989). Fast-grown plantations tend to be harvested in short age rotations which results in higher proportions of juvenile wood. Juvenile wood typically exhibits lower stiffness and strength and may not meet the performance requirements for dimension lumber (Larson et al. 2001; MacPeak et al. 1990; Kretschmann 2010).

A simple and fast way to identify lumber that contains high percent of juvenile wood is the presence of pith. However, this characteristic is not included in the visual grading rules (SPIB 2014). Many authors have reported that presence of pith number of rings per inch (RPI) and percentage of latewood (LW) are indicators of juvenile wood, which affects the density of the piece. In many cases, it is possible to identify the high strength pieces by eliminating those pieces that are low in density (Winandy and Boone 1988; Kretschmann and Bendtsen 1992; Tong et al. 2009; Dahlen et al, 2014). The objective of this study was to evaluate the effect of pith, number of rings per inch (RPI) and percentage of latewood (LW) on bending strength and stiffness of commercially produced southern pine 2 × 4 and 2 × 6 No. 2 grade lumber.

4.3 Material and methods

4.3.1 Test material

A sample of southern pine visually graded weight by production per region was collected from 15 of the original 18 southern pine growth regions (Jones 1989). A total of 363 pieces of 2 × 4, and 388 pieces of 2 × 6 No. 2 grade structural lumber was collected. The lumber was grade stamped from either the Southern Pine Inspection Bureau (SPIB) or Timber Products Inspection (TP) agencies. The sampling mimicked the in-grade lumber sampling used to derive design values by SPIB. No. 2 grade lumber was selected because it accounts for the largest volume of southern pine produced. A certified grader from either SPIB or TP regraded all specimens to assure that the sample were actually No.2 grade.

4.3.2 Specimen preparation and testing

The RPI and LW were measured at each end of each piece according SPIB (2014), and an average value for RPI and percent latewood was calculated and recorded for each piece. All six faces of the specimens were inspected in order to evaluate the presence of pith. If pith appeared on either half of the length it was considered as containing pith. The dimensions, weight, and moisture content (MC) of each specimen was recorded.

Edgewise bending tests were performed according to ASTM D 198 (2014c) via four-point loading on an Instron testing machine utilizing Bluehill 3 software, with a depth/span ratio of 17 to 1. The specimens were oriented randomly in the test fixture to better represent the actual in service use. The rate of loading was in accordance with ASTM D 4761 (2014b). The deflection was measured by a deflectometer in the mid span to determine MOE. MOR was calculated from the maximum load.

The adjustments of each piece for MOE to standard loading conditions, were according to ASTM D 1990 (2014d), ASTM D 2915 (2014a), and Evans et al. (2001). Then, data was adjusted to 15% MC and adjusted to four-point uniform loading. The MOR of each specimen was adjusted to 15% MC according to ASTM D 1990 (2014d). The allowable design bending strength (F_b) for the sample was calculated using the nonparametric 5th percentile at a 75% confidence interval and divided by 2.1 safety and load duration factor according to ASTM D 2915 (2014a) and Evans et al. (2001). The results found in this research for MOE and F_b were compared to the new and prior design value (SBPIB 2013) shown in Table 4.1.

Table 4.1 Previous and new design values for southern pine No. 2 grade lumber (AFPA 2005; ALSC 2013)

Lumber Size	Previous design value (2012 and prior)		New design value (2013 and after)	
	MOE (GPa)	F_b (MPa)	MOE (GPa)	F_b (MPa)
2 × 4	11.0	10.3	9.7	7.6
2 × 6		8.6		6.9

4.3.3 Statistical analysis

The statistical analyses and associated graphs were developed in SAS 9.4 (SAS Version 9.4, 2013) according to ASTM D 2915 (2014a). The mean, and coefficient of variation (COV) for RPI, LW, MOE and MOR were calculated. Pith, RPI, and LW were divided into groups to evaluate their effects, if any, on mechanical properties. Pith was divided into groups, specimens containing no pith, and specimens containing pith.

The cut off point for RPI and LW followed SPIB rules, where it allows No. 2 grade to have approximately 4 or more annual rings per inch on either end of the piece, or 1/3 average of summerwood. The two RPI groups were called upper RPI (specimens with RPI higher or equal to 4.0), and lower RPI (specimens with RPI lower than 4.0). The same was done for LW, upper LW group (specimens with LW higher or equal to 33.0%), and lower LW group (specimens LW lower than 33.0%). Statistically significant differences for MOE and MOR between pith, RPI and LW groups were found using PROC GLM at $\alpha = 0.05$ level.

4.4 Results and discussion

The results for pith, RPI and LW are presented in Table 4.2. Overall, 26 % of the specimens contained pith. The mean value for number of RPI was 4.8, and mean value for LW was 44.5%.

Table 4.2 Summary of presence of pith, number of rings per inch (RPI), percentage of latewood (LW) of No. 2 grade 2 × 4 and 2 × 6 southern pine lumber

Size	With Pith (%)	No Pith (%)	Rings per inch	Latewood (%)
2 × 4	21.5	78.5	4.9 (42.3%)*	44.0 (26.7%)
2 × 6	30.7	69.3	4.8 (46.7%)	45.0 (25.0%)
Overall	26.2	73.8	4.8 (44.4%)	44.5 (25.8%)

*Coefficient of variation (shown in parenthesis)

The overall results for MOE, MOR and F_b are shown in Table 4.3. The SG mean value was 0.54 with a range from 0.49 to 0.57. The MOE mean value was 9.9 GPa, with a range from 8.3 GPa to 11.2 GPa 10.2 GPa. The mean value for MOR was 46.1 MPa, and it ranged from 31.3 MPa to 55.8 MPa for 2 × 6. After analyzing the data according to ASTM D 1990 (2014), the F_b yielded in this research was 11.2 MPa for 2 × 4, and 9.2 MPa for 2 × 6.

Table 4.3 Summary of specific gravity, modulus of elasticity (MOE), and modulus of rupture (MOR) of No. 2 grade 2 × 4 and 2 × 6 southern pine lumber

Size	MOE (GPa)	MOR (MPa)	F_b (MPa)
2 × 4	10.2[b] (23.9%)[*]	51.1 (34.3%)	11.2[c]
2 × 6	9.7[b] (22.7%)	41.6 (37.8%)	9.2[c]
Overall	9.9 (23.5%)	46.1 (37.4%)	–

[*]Coefficient of variation (shown in parenthesis)
[a]Indicates MOE value met 2011 design value (11.0 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[b]Indicates MOE value met 2013 design value (9.7 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[c]Indicates F_b value met 2011 design value (8.6 MPa) after rounding to nearest 0.3 MPa ASTM D1990 (2014d)

4.4.1 Effect of pith groups on 2 × 4 and 2 × 6 specimens

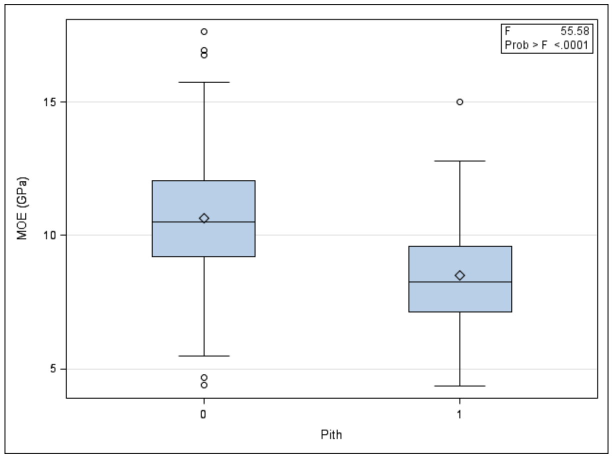
The mean values of MOE, MOR, and calculated F_b for 2 × 4, and 2 × 6 specimens are shown in Table 4.4.

Table 4.4 Effect of pith on modulus of elasticity (MOE), modulus of rupture (MOR), allowable design bending strength (F_b) in No. 2 2 × 4 and 2 × 6 southern pine lumber adjusted to 15% MC

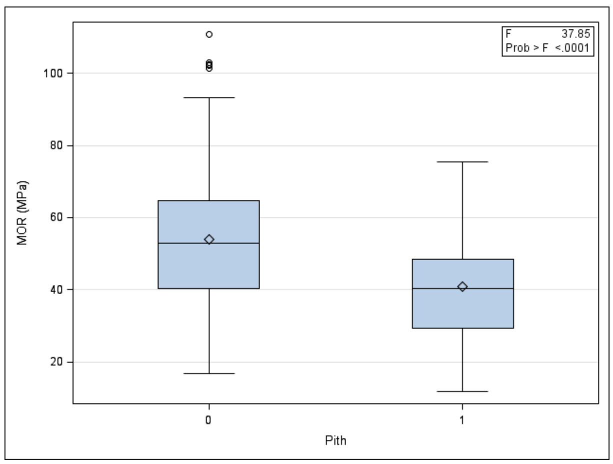
			2 × 4 Specimens		
Groups	N	Pith (%)	MOE (GPa)	MOR (MPa)	F_b (MPa)
No pith	285	78.5	10.7[a] (21.8%)**	54.0 (32.5%)	13.6[c]
Pith	78	21.5	8.5 (24.1%)	40.9 (32.2%)	10.8[c]
			2 × 6 Specimens		
Groups	N	Pith (%)	MOE (GPa)	MOR (MPa)	F_b (MPa)
No pith	269	69.3	10.1[b] (22.1%)	44.2 (36.4%)	9.5[c]
Pith	119	30.7	8.8 (21.4%)	35.1 (35.7%)	8.8[c]

*ns indicates no statistical difference at $\alpha = 0.05$ within sizes
**Coefficient of variation (shown in parenthesis)
[a]Indicates MOE value met 2011 design value (11.0 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[b]Indicates MOE value met 2013 design value (9.7 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[c]Indicates F_b value met 2011 design value (8.6 MPa) after rounding to nearest 0.3 MPa ASTM D1990 (2014d)

For 2 × 4 specimens, the mean values of MOE (10.7 vs. 8.5 GPa) and MOR (54.4 vs. 40.9 MPa) were significantly higher ($p < 0.0001$) for specimens containing pith, than specimens containing pith. Same trend was found for F_b, where specimens that containing no pith yielded higher F_b than the ones containing pith (13.6 vs. 10.8 MPa). The boxplots reinforce that specimens containing no pith were greater in MOE, and MOR than specimens containing pith (Figure 4.1)



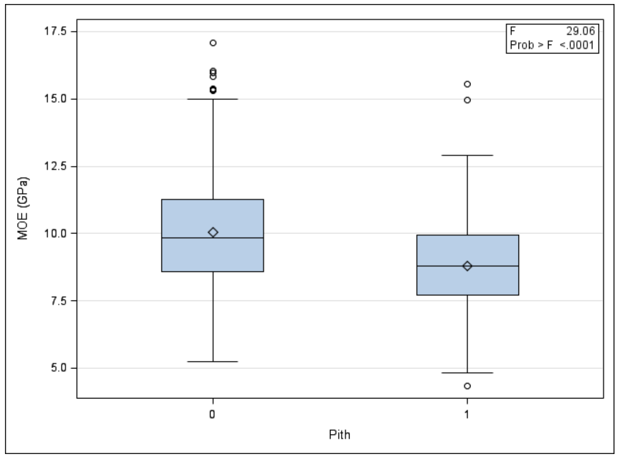
(a)



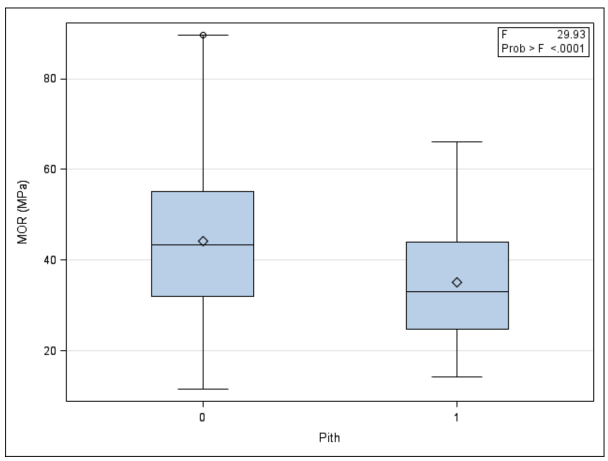
(b)

Figure 4.1 Boxplots of specimens contacting pith and containing no pith for (a) modulus of elasticity (MOE); (b) modulus of rupture (MOR)

The same trend was found for 2 × 6 specimens, where the mean values for MOE (10.1 vs. 8.8 GPa), and MOR (44.2 vs. 35.1 MPa) were significantly higher ($p < 0.0001$) for specimens containing no pith (Figure 4.2). The F_b value (9.5 vs. 8.8 MPa) for specimens containing no pith was also higher than specimens containing pith.



(a)



(b)

Figure 4.2 Boxplots of lumber with pith and lumber without pith for (a) modulus of elasticity (MOE); (b) and modulus of rupture (MOR) of No. 2 2 × 6 southern pine lumber

4.4.2 Effect of numbers of rings per inch groups on 2 × 4 and 2 × 6 specimens

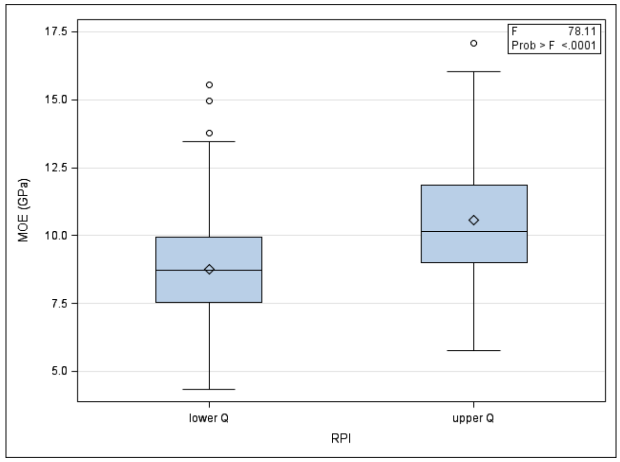
The mean values of MOE, MOR, and calculated F_b for 2 × 4, and 2 × 6 specimens are shown in Table 4.5.

Table 4.5 Effect of number of rings per inch on modulus of elasticity (MOE), modulus of rupture (MOR), and allowable design bending strength (F_b) in No. 2 2 × 4 and 2 × 6 southern pine lumber adjusted to 15% MC

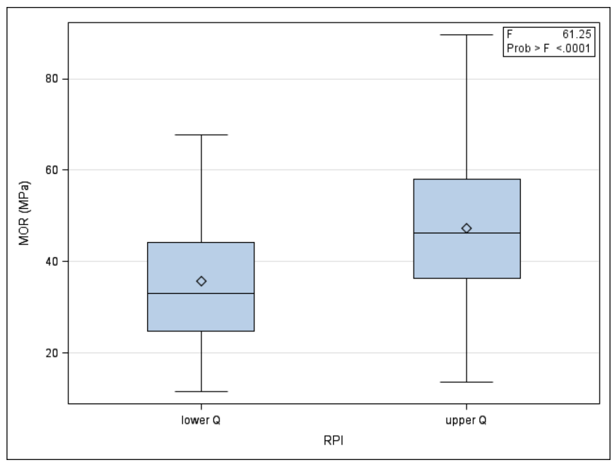
2 × 4 Specimens					
Groups	N	RPI	MOE (GPa)	MOR (MPa)	F_b (MPa)
Upper RPI	216	≥ 4.0	11.2[a] (19.7%)[**]	55.8 (32.3%)	14.3[c]
Lower RPI	147	< 4.0	8.7 (21.8%)	44.1 (31.8%)	12.5[c]
2 × 6 Specimens					
Groups	N	RPI	MOE (GPa)	MOR (MPa)	F_b (MPa)
Upper RPI	269	≥ 4.0	10.7[b] (20.3%)	47.2 (33.2%)	10.2[c]
Lower RPI	119	< 4.0	8.8 (21.2%)	35.6 (37.4%)	8.4[c]

[*]ns indicates no statistical difference at $\alpha = 0.05$ within sizes
[**]Coefficient of variation (shown in parenthesis)
[a]Indicates MOE value met 2011 design value (11.0 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[b]Indicates MOE value met 2013 design value (9.7 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[c]Indicates F_b value met 2011 design value (8.6 MPa) after rounding to nearest 0.3 MPa ASTM D1990 (2014d)

For 2 × 4 specimens, the MOE (11.2 vs. 8.7 GPa), and MOR (55.8 vs. 44.1 MPa) were significantly higher ($p < 0.0001$) for specimens with RPI higher or equal to 4.0. As expected, the F_b of specimens in the upper RPI group was higher than specimens in the lower RPI group (14.3 vs. 12.5 MPa). The boxplots of MOE and MOR for lumber in the upper RPI group and lower RPI group (Figures 4.3).



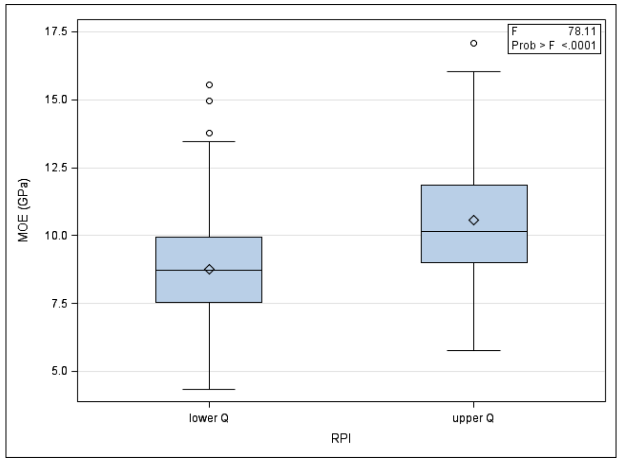
(a)



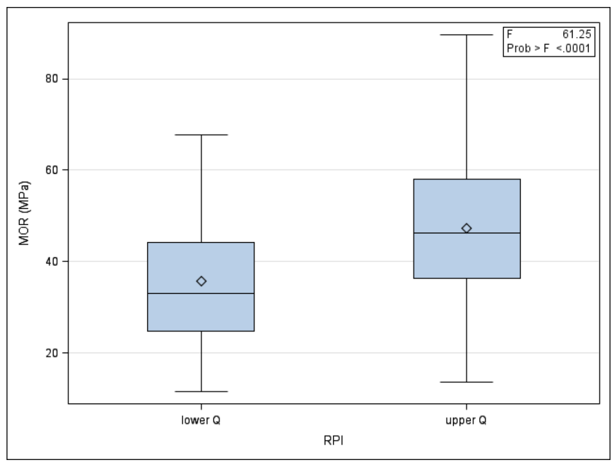
(b)

Figure 4.3 Boxplots of lumber in upper and lower classes of rings per inch for (a) modulus of elasticity (MOE); (b) and modulus of rupture (MOR) of No. 2 2 × 4 southern pine lumber

For 2 × 6, the MOE (10.7 vs. 8.8 GPa), and MOR (47.2 vs. 35.6 MPa) of specimens in the uuper RPI group were significantly greater ($p < 0.0001$) than specimens in the lower RPI group. The F_b value of the specimens in the upper RPI group was higher than specimens in the lower RPI group (10.2 vs. 8.4 MPa). The boxplots for MOE and MOR with specimens in the upper RPI groups versus specimens in the lower RPI groups are shown in Figure 4.4.



(a)



(b)

Figure 4.4 Boxplots of lumber in upper and lower classes of rings per inch for (a) modulus of elasticity (MOE); (b) and modulus of rupture (MOR) of No. 2 2 × 6 southern pine lumber

4.4.3 Effect of latewood groups on 2 × 4 and 2 × 6 specimens

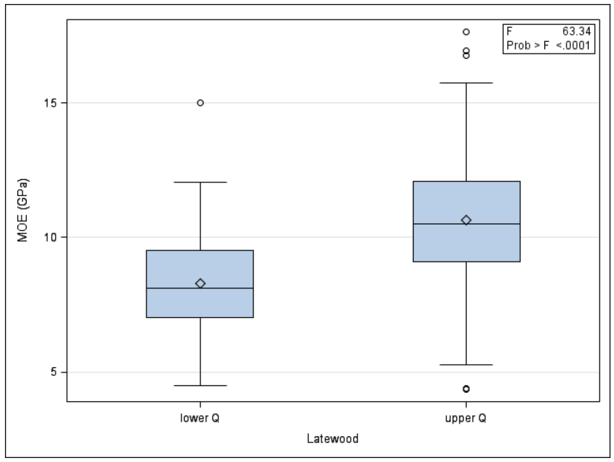
The effect of LW groups on MOE, MOR, and calculated F_b for 2 × 4, and 2 × 6 specimens are shown in Table 4.5.

Table 4.6 Effect of percentage of latewood on modulus of elasticity (MOE), modulus of rupture (MOR), and alloweable design bending strength (F_b) in No. 2 2 × 4 and 2 × 6 southern pine lumber adjusted to 15% MC

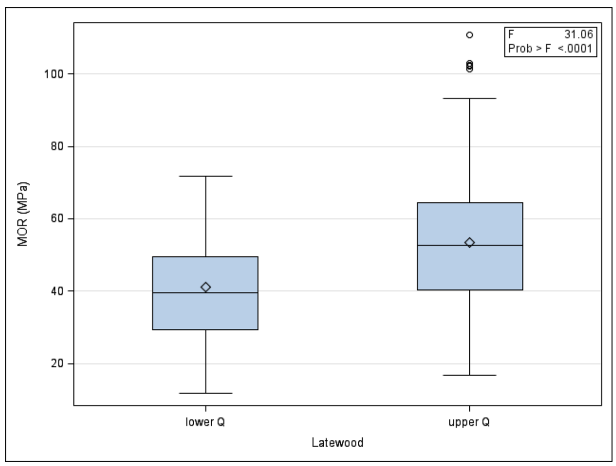
			2 × 4 Specimens		
Groups	N	LW	MOE (GPa)	MOR (MPa)	F_b (MPa)
Upper RPI	216	≥ 33.0	10.7[a] (21.0%)	53.5 (32.8%)	13.5[c]
Lower RPI	147	˂ 33.0	8.3 (22.9%)	41.1 (32.6%)	11.6[c]
			2 × 6 Specimens		
Groups	N	LW	MOE (GPa)	MOR (MPa)	F_b (MPa)
Upper RPI	269	≥ 33.0	9.9[b] (22.2%)	43.6 (35.6%)	10.2[c]
Lower RPI	119	˂ 33.0	8.4 (20.0%)	31.3 (32.3%)	7.8[c]

[*]ns indicates no statistical difference at $\alpha = 0.05$ within sizes
[**]Coefficient of variation (shown in parenthesis)
[a]Indicates MOE value met 2011 design value (11.0 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[b]Indicates MOE value met 2013 design value (9.7 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[c]Indicates F_b value met 2011 design value (8.6 MPa) after rounding to nearest 0.3 MPa ASTM D1990 (2014d)

For 2 × 4 specimens, the MOE (10.7 vs. 8.3 GPa) and MOR (53.5 vs. 41.1 MPa) were significantly higher ($p < 0.0001$) for pieces that had LW higher or equal to 33.0%. The F_b for specimens in the upper LW group was higher than specimens in the lower LW group (13.5 vs. 11.6 MPa). The boxplots reinforce that specimens in the upper LW group were significantly higher in MOE and MOR than specimens in the lower LW group (Figure 4.5).



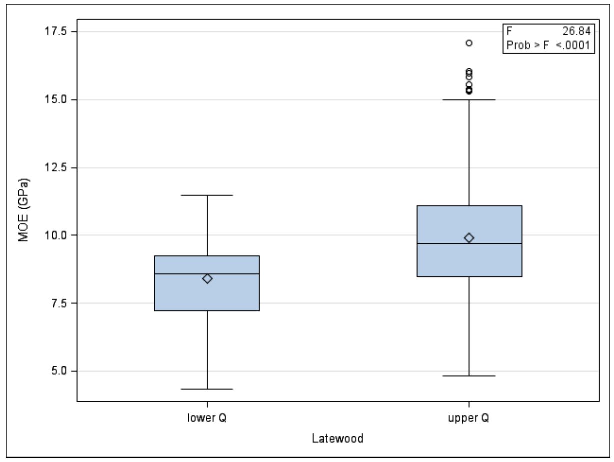
(a)



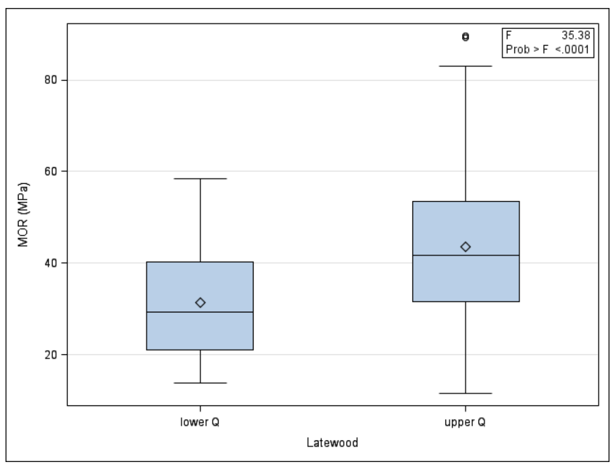
(b)

Figure 4.5 Boxplots of lumber in upper and lower classes of percentage of latewood for (a) modulus of elasticity (MOE); (b) and modulus of rupture (MOR) of No. 2 2 × 4 southern pine lumber

For 2 × 6 specimens, the SG (0.55 vs. 0.50), MOE (9.9 vs. 8.4 GPa) and MOR (43.6 vs. 31.3 MPa) were significantly higher ($p < 0.0001$) for pieces with LW higher or equal to 33.0%. The F_b value of specimens in the upper LW group was higher than specimens in the lower LW group (10.2 vs. 7.8 MPa). The boxplots illustrate the differences in stiffness and strength for specimens in the upper LW and lower LW are shown in Figure 4.6.



(a)



(b)

Figure 4.6 Boxplots of lumber in upper and lower classes of rings per inch for (a) modulus of elasticity (MOE); (b) and modulus of rupture (MOR) of No. 2 2 × 6 southern pine lumber

For the 2 × 4 size, specimens with no pith, RPI higher or equal to 4.0, and LW higher or equal to 33.0% displaced MOE (11.0 GPa) greater than the previous design value. However, specimens with pith, and RPI lower than 4.0, and LW lower than 33.0% were below the new design value for MOE (9.7 GPa). For F_b value, all groups exceeded the new (7.6 MPa) and previous design value (10.3 MPa).

For the 2 × 6 size, the mean MOE for specimens that contained pith, RPI higher or equal to 4.0 and LW higher or equal to 33.0% was less than new (published) design value (9.7 GPa). Specimens that contained no pith and presented LW higher or equal to 33.0% were similar to the new design value after rounding according to ASTM D 1990 (2014), while specimens with RPI lower than 4.0 met previous design value after rounding according to ASTM D1990 (2014). The F_b value of all groups exceeded the previous (SPIB 2012 and prior) design value (8.6 MPa).

The mean value for MOE and MOR for specimens that contained no pith, RPI higher or equal to 4.0, and LW higher or equal to 33.0% were similar to the overall mean value found in prior tests conducted southern pine lumber (Doyle and Markwardt 1966) (11.2 GPa and 46.8 MPa, respectively). The found mean values of MOE (10.1 GPa) and MOR (54.7 MPa) found by Bendsten et al. (1972) were also comparable to the MOE and MOR mean value found in this study. The overall mean value of MOE and F_b values found herein were higher than the values in 2 × 4 southern pine lumber found by Dahlen et al. (2014) 11.0 GPa and 9.1 MPa, respectively.

4.5 Conclusion

This study shows that presence of pith when combined with RPI and LW required on the grade rules improves the visual grading process. For 2 × 4 and 2 × 6, specimens that contained no pith and had RPI higher or equal to 4.0 and LW higher or equal to 33.0% LW yielded greater mean values of MOE and MOR. The results indicate that lumber containing no pith has higher RPI and higher LW and yields higher SG and higher MOE and MOR values than lumber containing pith, and were in the lower RPI and lower LW category. During the grading process, this information could be used to downgrade the weaker pieces. Being able to identify the lower strength and stiffness pieces can have a positive effect on the quality of southern visually graded lumber.

4.6 References

AFPA. 2005. National design specification (NDS) for wood construction with commentary and supplement: Design values for wood construction 2005 edition. American Forest & Paper Association, Washington, DC.

American Lumber Standards Committee – ALSC. 2014. American Lumber Standard Committee Board of Review: Board of Review Minutes. February 1, 2013. American Lumber Standards Committee, Germantown, MD.

American Society for Testing and Materials. 2014a. D 2915. Standard practice for sampling and data-analysis for structural wood and wood-based products.. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014b. D 4761. Standard test methods for mechanical properties of lumber and wood-base structural material. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014c. D 198. Standard test methods of static tests of lumber in structural sizes. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014d. D 1990. Standard practice for establishing allowable properties for visually-graded dimension lumber from in-grade tests of full-size specimens. ASTM International, West Conshohocken, PA.

Antony F, Schimleck LR, Daniels RF, Clark III A, Borders BE, Kane MB, Burkhart HE. 2015. Whole-tree bark and wood properties of loblolly pine from intensively managed plantations. Forest Science 61(1):55-66.

Bendtsen BA, Ethington RL, Galligan WL. 1972. Properties of major southern pines: Part II Structural properties and specific gravity. USDA Forest Service. Forest Products Laboratory. FPL-GTR-177. Madison, WI. 76 p.

Blass H and Frese M. 2004. Combined visual and machine strength grading. Holz Roh-Werkst 62:325–334.

Dahlen J, Jones PD, Seale RS, Shmulsky R. 2014. Bending strength and stiffness of wide dimension southern pine No. 2 lumber. European Journal of Wood and Wood Products 72(6):759-768.

Doyle DV and Markwardt LJ. 1966. Properties of southern pine in relation to strength grading dimension lumber. USDA Forest Service. Forest Products Laboratory. FPL-64. Madison, WI. 62 p.

Evans JW, Kretschmann DE, Hatfield CA, Green DW. 2001. Procedures for developing allowable properties for a single species under ASTM D1990 and computer programs useful for the calculation. USDA Forest Service. Forest Products Laboratory. FPL-GTR-126. 42 p.

Jones E. 1989. Sampling procedures used in the in-grade lumber testing program. Pages: 11-14. *In*: DW Green, BE Shelley, and HP Vokey, eds. Proceedings of workshop sponsored by In-grade Testing Committee and Forest Products. Proceedings 47363. USDA Forest Service. Forest Products Laboratory. Madison, WI.

Kimball KE and Lowery DP. 1967. Quality of studs dried by high and conventional temperature. Forest Products Journal 17(9):81-85.

Kretschmann DE and Hernandez R. 2006. Grading timber and glued structural members. *In*: Walker J. ed., Primary Wood Processing 2nd ed., pp. 339–390.

Kretschmann DE and Bendtsen BA. 1992. Ultimate tensile stress and modulus of elasticity of fast-grown plantation loblolly pine lumber. Wood and Fiber Science 24(2):189-203.

Kretschmann DE, Evans JW, Brown L. 2010. Stress Grades and Design Properties for Lumber, Round Timber and Ties. Pages 7-1-7-16. *In*: Ross RJ ed., Wood Handbook. USDA Forest Service. Forest Products Laboratory. FPL-GTR-190. Madison, WI.

Larson PR, Kretschmann DE, Clark A. III, Isen-brands J.G. 2001. Juvenile wood formation and proper-ties in southern pine. USDA Forest Service. Forest Products Laboratory. FPL-GTR-129. Madison, WI. 42 p.

MacPeak MD, Burkhart LF, Weldon D. 1990. Comparison of grade, yield and mechanical properties of lumber produced from young fast-grown and older slow-grown planted slash pine. Forest Products Journal 40(1):11-14.

Madsen B and Nielsen LF. 1992. Structural Behavior of Timber. Timber Engineering Ltd., North Vancouver, British Columbia, Canada. 405 p.

SAS Institute. 2013. SAS® software, version 9.4. The SAS Institute Inc. Cary, NC.

Southern Pine Inspection Bureau – SPIB. 2014. Standard Grading Rules for Southern Pine Lumber. Southern Pine Inspection Bureau, Pensacola, FL.

Tong Q-J, Fleming RL, Tanguay F, Zhang SY. 2009. Wood and lumber properties from unthinned and precommerciallly thinned black spruce plantations. Wood and Fiber Science 41(2):168-179.

Winandy JE and Boone RS. 1988. The effects of CCA preservative treatment and redrying on the bending properties of 2 × 6 southern pine lumber. Wood and Fiber Science 20(3):350-364.

Zobel BJ and Van Buijtenen JP. 1989. Wood Variation: Its Causes and Control. Berlin, Spirnger-Verlag, Heidelberg, DE. 418 p.

CHAPTER V

FLEXURAL PROPERTIES OF VISUALLY GRADED SOUTHERN PINE STRUCTURAL LUMBER

5.1 Abstract

The objective of this study was to evaluate the flexural properties of visually graded southern pine structural lumber. A total of 751 specimens of No 2 grade, 2 × 4 and 2 × 6 southern pine lumber obtained from a broad spectrum of regions in the southeastern United States. A certified grader evaluated all specimens to ensure that the specimens met appropriate grading criteria. Actual dimensions, weight, and moisture content (MC) were measured. Growth and manufacturing related characteristics were identified and classified into two categories: strength reducing characteristics (SRC) and grade reducing characteristics (GRC). Specific gravity (SG), bending modulus of elasticity (MOE), and modulus of rupture (MOR), were determined for each specimen. The average specific gravity value for the sample was 0.54. The sample's average MOE was 9.9 GPa, and its' average MOR was 46.1 MPa. The presence of knots was identified as the most significant SRC; their presence had the most significant impact on SG, MOE and MOR. For GRC, specimens with 'other' and and specimens that fell in the 'none' category were significantly lower in SG, MOE and MOR.

5.2 Introduction

The southern U.S. has large scale timber and lumber production which makes this region the most important lumber producer in the U.S. (Wear and Greis 2002; McKeand et al. 2003). Most of the southern pine wood is used for structural lumber because it is readily available, sustainable, strong, dries rapidly and can be easily treated. Southern pine wood products have a significant contribution to economic and ecological values of the region (AWC 2012; Jordan et al. 2008; Coyle et al. 2015).

Because wood is a material with wide variability in mechanical properties, there are many challenges associated with visually grading lumber for structural purposes. Structural lumber production requires methods to establish allowed properties, and simple ways to minimize variability with grading material is sorted into categories called stress grades. In the U.S., visual grading has historically been used to assign strength and stiffness properties to structural lumber (Ritter 1990; Kretschmann 2010).

The demand for wood products has been increasing since the end of the 2008 housing recession; this growth is due to increase in population and disposable income (Oswalt et al. 2010). Grading of structural lumber has long been recognized as an essential marketing practice, both from the standpoint of promoting safety in design and improving efficiency of utilization (Doyle and Markwardt, 1966). The profitability of a sawmill that produces visually graded lumber is influenced by many factors including lumber quality and size, and how well the raw material is processed (Brännström 2009). Finding new ways to improve the grading system is still a challenge for wood industry (Doyle and Markwardt 1966).

Visually graded lumber is classified based on growth and production characteristics known as Grading Rules. This method is the origin of stress grading for structural lumber. Visual grading accounts for the fact that mechanical properties of lumber differ from clear wood because of the effect of growth and production characteristics. These characteristics are macroscopic and can be judged visually. These macroscopic characteristics are the used to assign allowable strength class. The most common visual sorting criteria are knots, slope of grain, shake, checks and splits, density, decay, heartwood and sapwood, pitch pockets, wane, growth rate, and pith (Piazza and Riggio 2008; Kretschmann 2010).

The objectives of this study were to (1) determine the strength and stiffness in the 2 × 4 and 2 × 6 lumber commercially produced across southern pine growth regions; (2) determine the influence of sawing orientation on SG (specific gravity), MOE (modulus of elasticity) and MOR (modulus of rupture); (3) determine the effect of grade controlling characteristics on SG, MOE, MOR, and an allowable design bending strength (F_b).

5.3 Material and methods

5.3.1 Test material

A weighted production sample of southern pine lumber specimens was obtained and used in this study. A total of 751 lumber specimens were collected. The specimens were nominally two inches thick, and either four or six inches in width (2 × 4 and 2 × 6). All specimens were selected randomly from various geographical regions spread across the southern United States. All the specimens were visually graded as No. 2. This lumber size and grade combination was chosen because it represents the largest volume of southern pine lumber produced and used by size and grade (SFPA 2005). The specimens were transported to the testing laboratory of the Department of Sustainable Bioproducts, Mississippi State University, Starkville, MS. All specimens were evaluated by a certified grader in the laboratory to insure they met appropriate grade criteria.

5.3.2 Specimen preparation

The following was measured and determined for each specimen: cross sectional dimensions, weight, SG, and moisture content (MC). Specific attention was placed on growth ring orientation within a specimen's cross section. It was noted if the specimen was either flatsawn (growth rings tangent to the wide face of the specimen) or quartersawn (growth rings perpendicular to the wide face of the specimen). The certified grader identified grade and strength controlling characteristics for each piece.

The edgewise bending test setup was conducted according to ASTM D 198 (2014c) via four-point loading and a span-to-depth ratio of 17 to 1. The tension face and the characteristics were randomly selected without respect to their location between load heads (ASTM D 4761 2014b). Load and displacement were continuously monitored using a calibrated load cell and displacement monitoring setup. MOE and MOR were determined for each specimen from their corresponding load versus deflection data.

A series of calculations were performed to adjust the measured MOE and MOR values for comparative purposes. Previous studies, and currently used design values, report values that are adjusted to a moisture content level of 15% (Evans et al. 2001; ASTM D 1990 2014d). The F_b yielded in this research was calculated using the nonparametric 5th percentile at 75% confidence and divided by 2.1safety factor (ASTM D 2915 2014a; Evans et al. 2001). The SG of each piece was adjusted to MC 15%.

5.3.3 Statistical analysis

The statistical analysis and associated graphics were done using SAS 9.4 (2013) according to ASTM D 2915 (2014a). The mean, median and coefficient of variation (COV) were calculated for SG, MOE and MOR.

5.4 Results and discussion

The MC of the specimens averaged 11.1%, and ranged from 6.0 to 17.0%. Results obtained from static bending tests performed on the specimens are summarized in Table 5.1. The sample had an average specific gravity of 0.54. There was no significant difference in the average SG (p = 0.5640) values observed for the two widths of lumber used. The mean MOE was found to be 9.9 GPa. The mean value of MOE by size ranged from 10.2 GPa for the 2 × 4 specimens and 10.9 GPa for 2 × 6 specimens. The mean MOR value for the entire sample was 46.1 MPa. A MOR mean value of 51.1 MPa was found for the 2 × 4 specimens. The average MOR value observed for the 2 × 6 specimens was 41.6 MPa. There was significant difference between sizes for MOE (p = 0.0020) and MOR ($p < 0.0001$) mean values. The F_b value ranged from 11.2 MPa to 9.2 MPa for 2 × 4 and 2 × 6, respectively.

Table 5.1 Summary statistics for specific gravity (SG), modulus of elasticity (MOE), modulus of rupture (MOR) and bending strength (F_b) for No. 2 grade, from 2 × 4 and 2 × 6 southern pine lumber by size.

Size	Specific Gravity			MOE (GPa)			MOR (MPa)			F_b (MPa)
	Mean	Median	COV (%)	Mean	Median	COV (%)	Mean	Median	COV (%)	
2 × 4	0.55[ns]	0.54	11.4	10.2	10.2	23.9	51.1	49.7	34.3	11.2[c]
2 × 6	0.54	0.53	10.9	9.7	9.3	22.7	41.6	40.4	37.8	9.2[c]
Overall	0.54	0.53	11.2	9.9	9.7	23.5	46.1	44.4	37.4	–

[*]ns indicates no statistical difference at α = 0.05 within sizes
[a]Indicates MOE value met 2011 design value (11.0 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[b]Indicates MOE value met 2013 design value (9.7 GPa) after rounding to nearest 0.7 GPa ASTM D1990 (2014d)
[c]Indicates F_b value met 2011 design value (8.6 MPa) after rounding to nearest 0.3 MPa ASTM D1990 (2014d)
[d]Indicates F_b value met 2013 design value (6.9 MPa) after rounding to nearest 0.3MPa ASTM D1990 (2014d)

The grade controlling characteristics were divided into two categories, strength reducing characteristics (SRC) and grade reducing characteristic (GRC). The sample size and percentage of SRC and GRC for overall sample and each size are shown in Table 5.2. Before the analysis, controlling characteristics that had a sample size less than 10 were grouped into 'other' category for statistics and graphing purposes. For SRC the controlling characteristics were knot, none (no SRC), slope of grain, wane, and other (compression wood, handling damage, decay, saw cut, split, undersize and worm pitch). For GRC the controlling characteristics were knot, none (no GRC), skip, slope of grain, wane, warp, and other (compression wood, handling damage, decay, mechanical damage, saw cut, split, undersize and wormy pitch). The major controlling characteristic in SRC was knot representing 86% and only 1.5% of the specimens fell into the category none, which means that these specimens did not present any SRC, followed by the category other (1.7%).

Table 5.2 Percentage and sample size (n) for presence of pith and piece's orientation, strength reducing characteristic and grade reducing characteristic of No. 2 grade, from 2 × 4 and 2 × 6 southern pine lumber

Strength Reducing Characteristic			
Characteristic	2 × 4	2 × 6	Overall
Knot	85.7 (n = 311)	86.3 (n = 335)	86.0 (n = 646)
None	0.6 (n = 2)	2.3 (n = 9)	1.5 (n = 11)
Other	2.5 (n = 9)	1.0 (n = 4)	1.7 (n = 13)
Slope	4.1 (n = 15)	5.4 (n = 21)	4.8 (n = 36)
Wane	7.2 (n = 26)	4.9 (n = 19)	6.0 (n = 45)
Grade Reducing Characteristic			
Characteristic	2 × 4	2 × 6	Overall
Knot	10.5 (n = 38)	22.2 (n = 86)	16.5 (n = 124)
None	41.9 (n = 152)	31.5 (n = 122)	36.5 (n = 274)
Other	0.8 (n = 3)	4.5 (n = 18)	2.8 (n = 21)
Shake	0.8 (n = 3)	1.6 (n = 6)	1.2 (n = 9)
Skip	3.9 (n = 14)	5.7 (n = 22)	4.8 (n = 36)
Slope	1.4 (n = 5)	0.5 (n = 2)	1.0 (n = 7)
Wane	27.0 (n = 98)	23.2 (n = 90)	25.0 (n = 188)
Warp	13.8 (n = 50)	10.8 (n = 42)	12.3 (n = 92)

*In same cases the grade-reducing characteristic is the strength reducing characteristic. In other case it is not. Due to randomized lengthwise positions, the grade-reducing characteristic was not always positioned between the load heads

The lumber from this study had an average SG value that was greater than that reported by Dahlen et al. (2014). It should be noted that the cited work only utilized 2 × 4 material. The mean SG value observed had similar characteristics of mature wood (Larson et al. 2001), and it was found to be slightly greater than that published for clear specimens of loblolly pine wood (FPL 2010).

The mean MOE value found for the sample was 9.9 GPa. The mean values of MOE for the 2 × 4 and 2 × 6 specimens were 10.2 GPa and 10.9 GPa, respectively. The difference was found to be statistically different. For 2 × 4 specimens, the MOE mean value met the previous design value (11.0 GPa), and it was similar to the previous study on southern pine 2 × 4 lumber (11.0 GPa) (Dahlen et al. 2014). The 2 × 6 specimens exceeded the current design value (9.7 GPa) (AFPA 2005, ALSC 2013) after rounding according to ASTM D1990 (2014d).

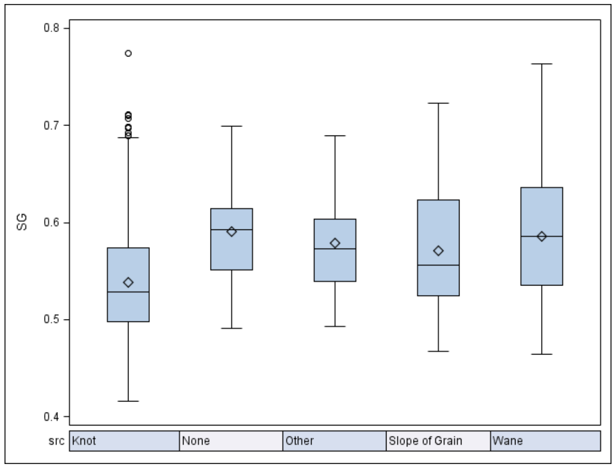
The overall mean value for MOR was 46.1 MPa, which is lower than the overall mean value MOR (48.3 MPa) found in prior tests of southern pine 2 × 4 lumber (Dahlen et al. 2014). The MOR mean value ranged from 51.1 MPa for 2 × 4 to 41.6 MPa for 2 × 6 specimens, the difference was found to be significant ($p < 0.0001$). As expected, the COV for MOR (44.4%) was found to be greater than MOE (23.5 %). The F_b value for 2 × 4 and 2 × 6 were 11.2 and 9.2 MPa respectively. The F_b value for both sizes are higher than previous and current design values. The F_b value for the 2 × 4 specimens was higher than the value found by Dahlen et al. (2014) (9.1 MPa).

Table 5.2 shows that effect of GRC on SG, MOE and MOR. The impact of SRC was statistically significant for SG ($p < 0.0001$), MOE ($p < 0.0001$) and MOR ($p < 0.0001$). The characteristic knot was significantly lower in SG (0.54), MOE (9.7 GPa) and MOR (43.8 MPa), and pieces that fell into none category had the highest mean value for SG (0.59), MOE (12.7 GPa) and MOR (61.2 MPa) (Table 5.2). The boxplots for SG, MOE, and MOR versus GRC are shown in Figure 4.

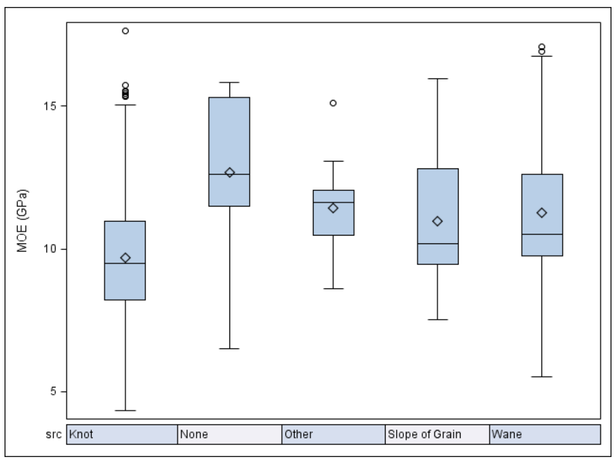
Table 5.3 Summary statistics of SG, MOE, and MOR of No. 2 grade southern pine lumber by strength reducing characteristic (SRC) in 2 × 4 and 2 × 6

SRC	N	SG			MOE (GPa)			MOR (MPa)		
		Mean	Median	COV	Mean	Median	COV	Mean	Median	COV
Knot	646	0.54b	0.53	10.8	9.7c	9.5	22.8	43.8c	42.3	36.6
None	11	0.59a	0.59	21.1	12.7a	12.6	21.1	61.2a	75.0	22.0
Other	13	0.58a	0.57	10.0	11.4ab	11.6	14.8	59.8ab	59.2	26.9
Slope	36	0.57a	0.56	11.5	11.0b	10.2	21.8	55.4b	53.4	27.8
Wane	45	0.59a	0.59	11.6	11.3ab	10.5	24.6	61.2ab	62.6	32.0

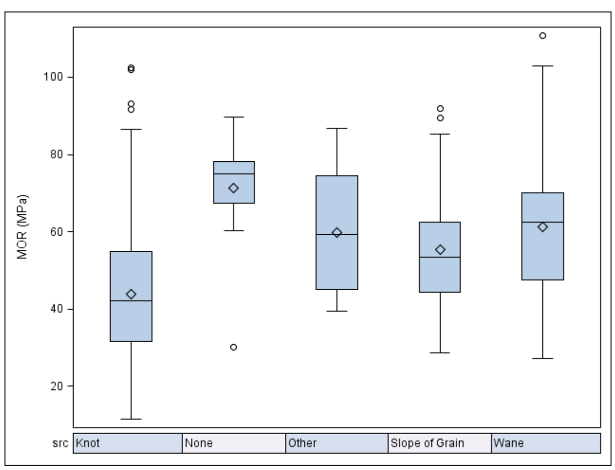
Significant difference strength reducing characteristic indicated by different letters at $\alpha = 0.05$



(a)



(b)



(c)

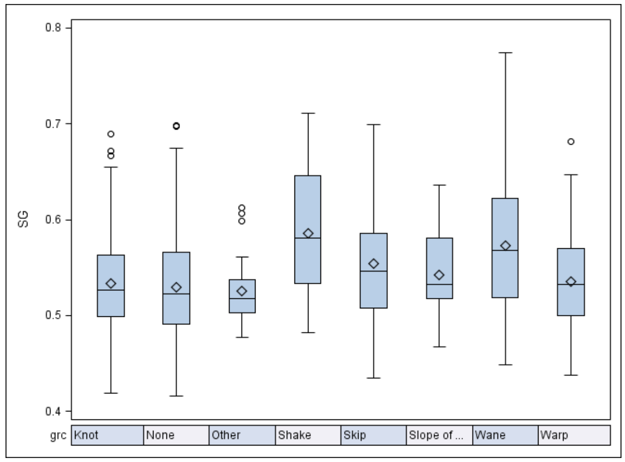
Figure 5.1 Boxplot of (a) specific gravity; (b) modulus of elasticity; and (c) modulus of rupture of 2 × 4 and 2 × 6 No. 2 grade southern pine lumber by grade reducing characteristic

The overall results for GRC are shown in Table 5.6. For GRC, most of the specimens fell into the ‘none’ category, which represents 36.5% of the specimens, followed by wane (25.0%). There was a significant impact of GRC in SG ($p < 0.0001$), MOE ($p < 0.0001$), and MOR ($p < 0.0001$). Pieces that fell into other category had the lowest SG (0.52), while pieces with warp showed the lowest mean value for MOE (8.9 GPa), and pieces in none the category had the lowest mean value for MOR (40.6 MPa). Pieces that contained shake had the highest mean value for SG (0.59), and pieces with wane had the highest mean value in MOE (11.3 GPa) and MOR (57.6 MPa). The boxplots for SG, MOE, and MOR versus GRC are shown in Figure 5.3.

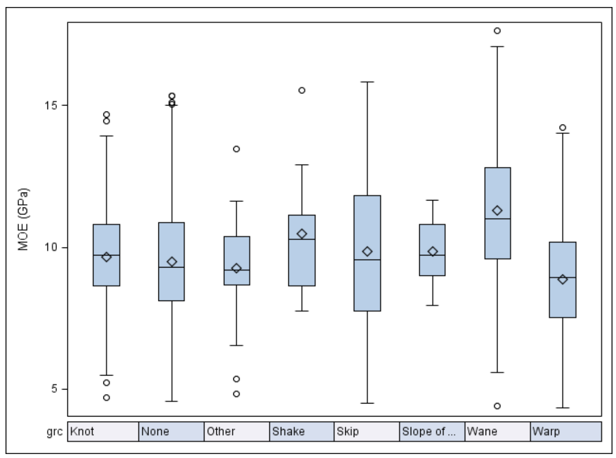
Table 5.4 Summary statistics of SG, MOE, and MOR of No. 2 grade southern pine lumber by grade reducing characteristic (GRC) in 2 × 4 and 2 × 6

GRC	N	SG			MOE (GPa)			MOR (MPa)		
		Mean	Median	COV (%)	Mean	Median	COV (%)	Mean	Median	COV (%)
Knot	124	0.53b	0.52	10.1	9.7bc	9.7	19.8	41.5b	42.0	37.0
None	274	0.53b	0.52	10.3	9.5bc	9.3	22.7	40.6b	38.8	36.6
Other	21	0.52b	0.52	7.7	9.3bc	9.2	22.2	41.5b	41.0	36.2
Shake	9	0.59a	0.58	13.8	10.5ab	10.3	23.8	47.3ab	45.6	30.3
Skip	36	0.55ab	0.55	11.9	9.9ab	9.6	26.5	48.6ab	48.1	41.1
Slope	7	0.54ab	0.53	9.8	9.9abc	9.7	12.2	49.5ab	48.5	15.3
Wane	188	0.57a	0.57	11.7	11.3a	11.0	21.0	57.6a	57.6	30.0
Warp	92	0.54b	0.53	9.6	8.9c	9.0	23.3	44.8b	42.3	33.7

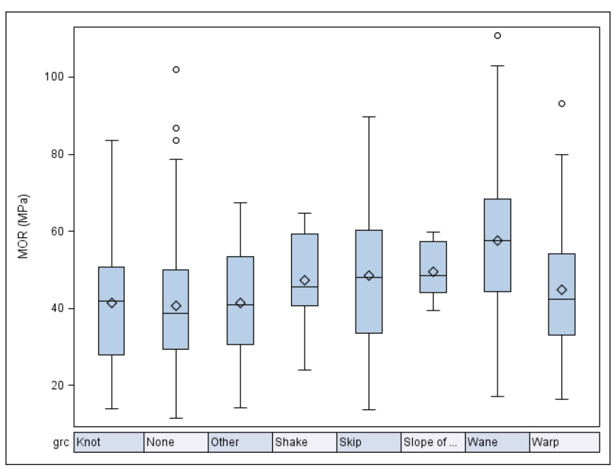
Significant difference grade reducing characteristic indicated by different letters at $\alpha = 0.05$



(a)



(b)



(c)

Figure 5.2 Boxplot of (a) specific gravity; (b) modulus of elasticity; and (c) modulus of rupture of 2 × 4 and 2 × 6 No. 2 grade southern pine lumber by grade reducing characteristic

5.5 Conclusion

This study investigated the effect of grade controlling characteristics on SG, MOE, and MOR. Results revealed the following:

- For SRC, lumber with knots had the lowest SG, stiffness and strength values
- Lumber that fell into the 'none' group had the highest mean values of SG, MOE, and MOR.
- For the GRC, specimens containing shake and wane were greater in SG, MOE, and MOR.
- Specimens that were grouped into 'other' and 'none' categories had greater SG, MOE, and MOR.

5.6 References

AFPA. 2005. National design specification (NDS) for wood construction with commentary and supplement: Design values for wood construction 2005 edition. American Forest & Paper Association, Washington, DC.

American Lumber Standards Committee – ALSC. 2013. American Lumber Standard Committee Board of Review: Board of Review Minutes. February 1, 2013. American Lumber Standards Committee, Germantown, MD.

American Society for Testing and Materials. 2014a. D 2915. Standard practice for sampling and data-analysis for structural wood and wood-based products. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014b. D 4761. Standard test methods for mechanical properties of lumber and wood-base structural material. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014c. D 198. Standard test methods of static tests of lumber in structural sizes. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials. 2014d. D 1990. Standard practice for establishing allowable properties for visually-graded dimension lumber from in-grade tests of full-size specimens. ASTM International, West Conshohocken, PA.

American Wood Council. AWC. 2012. National design specification® (NDS®)for wood construction. Leesburg, Virginia.

Brännström M. 2009. The impact of a strength grading process on sawmill profitability and product quality. BioResources 4(4):1430-1454.

Coyle DR, Klepzig KD, Koch FH, Morris LA, Nowak JT, Oak SW, Otrosina WJ, Smith WD, and Gandhi KJ. 2015. A review of southern pine decline in North America, Forest Ecology and Management 349:134-148.

Dahlen J, Jones PD, Seale RS, Shmulsky R. 2014. Bending strength and stiffness of wide dimension southern pine No. 2 lumber. European Journal of Wood and Wood Products 72(6):759-768.

Doyle DV and Markwardt LJ. 1966. Properties of southern pine in relation to strength grading dimension lumber. USDA Forest Service. Forest Products Laboratory. FPL-64. Madison, WI. 62 p.

Evans JW, Kretschmann DE, Hatfield CA, Green DW. 2001. Procedures for developing allowable properties for a single species under ASTM D1990 and computer programs useful for the calculation. USDA Forest Service. Forest Products Laboratory. FPL-GTR-126. 42 p.

FPL. 2010. Wood Handbook – Wood as engineering material. USDA Forest Service. Forest Products Laboratory. FPL-GTR-190. Madison, WI. 508 p.

Jordan L, Alexander III C, Schimleck LR, Hall DB, and Daniels RF. 2008. Regional variation in wood specific gravity of planted loblolly pine in the United States. Canadian Journal of Forest Resources 38:678-710.

Kretschmann DE, Evans JW, Brown L. 2010. Stress Grades and Design Properties for Lumber, Round Timber and Ties. Pages 7-1-7-16. *In*: Ross RJ ed., Wood Handbook. USDA Forest Service. Forest Products Laboratory. FPL-GTR-190. Madison, WI.

Larson PR, Kretschmann DE, Clark A. III, Isen-brands J.G. 2001. Juvenile wood formation and proper-ties in southern pine. USDA Forest Service. Forest Products Laboratory. FPL-GTR-129. Madison, WI. 42 p.

McKeand S, Mullin T, Byram T, and White T. 2003. Deployment of genetically improved loblolly and slash pine in the south. Journal of Forestry 100(3):32-37.

Oswalt SN, Thompson M, and Smith WB. 2010. US forest resource facts and historical trends. Available online at http://fia.fs.fed.us; last accessed July. 17, 2016.

Piazza M and Riggio M. 2008. Visual strength-grading and NDT of timber in traditional structures. Journal of Building Appraisal 3(4):267-296.

Ritter MA. 1990. Timber Bridges: Design, Construction, Inspection, and Maintenance -- Entire Publication. United States Department of Agriculture, Forest Service, Washington, DC: 944 p.

SAS Institute (2013) SAS® software, version 9.4. The SAS Institute Inc. Cary, NC.

Southern Forest Pine Association – SFPA. 2005. Industry statistics: annual production from 2000 to 2005 (White Paper). Southern Pine Forest Products Association, Kenner, La.

Wear DN and Greis JG. 2002. Southern Forest Resource Assessment: Summary of findings. Journal of Forestry 100(7):6-14.

CHAPTER VI

CONCLUSION

This study presented a picture of production weighted sample of No. 2 grade, 2 × 4, 2 × 6, 2 × 8, and 2 × 10 southern pine lumber collected from 15 of the original 18 regions spread across the southern U.S. More than 30% of the specimens contained pith, and averaged 4.6 of number of rings per inch (RPI), and 43.8% of latewood (LW). The RPI and LW of the specimens tested adequately met the requirements for No. 2 grade southern pine lumber (SPIB 2014). The specific gravity (SG) mean value was 0.54, with little variation among sizes. The overall modulus of elasticity (MOE) and modulus of rupture (MOR) were 10.1 GPa, and 41.7 MPa, respectively. The allowable design bending strength (F_b) obtained in this research for 2 × 4, 2 × 6, 2 × 8, and 2 × 10 was 11.2, 9.2, 8.1, and 7.1 MPa, respectively. The mean modulus of elasticity (MOE) value found in this research was comparable to the new and previous design value. The F_b of all sizes tested exceeded the new published design value, and met the previous design value.

Specimens containing no pith, RPI higher than 4.0, and LW higher or equal to 30% yielded higher MOE, MOR, and F_b values than specimens containing pith, RPI lower than 4.0, and LW lower than 33.0%. The results show that combining pith with the required RPI and LW can improve the prediction of bending strength and stiffness.

The grading controlling characteristics were studied in order to evaluate its effect on SG, MOE, and MOR. The grading controlling characteristic with the most impact on mechanical properties was knots. On the other hand, specimens that contained shake and wane were greater in SG, MOE, and MOR mean values.

The results yielded in this research suggest that the current lumber source has higher quality than the lumber used in previous tests in 2010 during houses crisis. The findings also show that the combination of pith, and required RPI and LW can be used to improve the quality of visual grading system. These variables are easy and quickly to be identified during the grading process.

Visual grading system still the most used system to grade lumber in the U.S, and efforts to improve the assessment of lumber should always be made and implemented. The information provided in this study can be used to select and to downgrade the weaker pieces, and to yield higher quality visually graded lumber. With an accurate grading system is possible to avoid over- or under-grading problems that can bring safety issues, and to reduce unnecessarily downgrading pieces thereby that cause needless economic loss.